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POTENTIAL FUTURE INITIATIVE DIRECTIONS IN NASA AERONAUTICS PROGRAMS

A REPORT PREPARED AT THE REQUEST OF
THE COMMITTEE ON SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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NATIONAL
AERONAUTICS AND
SPACE
ADMINISTRATION

EXECUTIVE SUMMARY

1. This paper responds to a request by the House of Representatives Committee on Science and Technology for a "white paper" concerning the potential for new initiatives in aeronautics. Using as an example NASA's Aircraft Energy Efficiency (ACEE) Program, the Committee suggested that the time is ripe for a bold new initiative directed at increasing productivity in air transportation and improving this Nation's competitive position and balance of trade.

2. NASA has reviewed current and projected aeronautics plans and programs to identify potential new focused initiatives which could accelerate progress toward the objectives cited by the Committee. These potential new focused initiatives, like the ACEE program, might be superposed over NASA's ongoing aeronautical research and technology programs to facilitate future development of improved U.S. civil aeronautical products.

3. This paper outlines the technical, market and economic factors that influence decisions as to the importance, the nature, the scope, and the timing of new focused initiatives as potential additions to NASA's ongoing programs. Also presented is an overview of cost and schedule implications of each potential initiative if it were to be added to the current NASA aeronautics program. The program options are presented as integrated total packages of effort applied to a specific area of opportunity. The major components of each program can in most instances be treated also as incremental activities providing lesser but nevertheless effective progress toward the desired technology advances.

4. Ongoing NASA programs, as presently constituted, include considerable activity in each of the areas cited as possible subjects for additional focus. Only the major aspects of these ongoing activities have been summarized in this paper, which is devoted primarily to consideration of possible options for expansions beyond the present activities.

5. Future focused program possibilities, addressing both near-term and far-term potential applications, emerge continuously from research and technology base and specific vehicle-oriented activities. The options discussed in this paper represent a snapshot of the major possibilities as seen at this time, rather than a set of specifically recommended programs. Evolution of the overall NASA aeronautics program will be based on future consideration of these possibilities and assessment of additional needs and opportunities perceived in the course of time.

6. The areas identified as credible candidates for potential near-term major additional emphasis, and the considerations relevant to the timing of possible new focused initiatives, are outlined briefly herein under the two primary categories of long haul and short haul/utility aircraft:

Long Haul	Short Haul/Utility
Subsonic Transports	Rotorcraft
Supersonic Transports	Commuter Transports
Large Cargo/Logistic Aircraft	General Aviation
Cryogenic-Fuel Transports	

Subsonic Transports

In the near term, new aircraft as well as derivatives of existing aircraft will be required in a rapidly expanding market. In the longer term, the potential exists for an era of new aircraft designs and concepts resulting in even greater productivity. Worthwhile new focused technical activity can be undertaken immediately, but a major new ACEE-type initiative is not required in the near future.

Supersonic Transports

The supersonic transport market is seen as less expansive than the subsonic market, but eventually very important. Both economic and possible environmental barriers combine to create an uncertain and high-risk situation. At the same time, the potential for productivity gains and the possibility of losing by default a major component of world aviation leadership suggest that increased supersonic technology effort may be warranted. The options discussed in the paper include progression from the present research level of activity to a large focused initiative directed at technology validation.

Large Cargo/Logistic Aircraft

New-technology dedicated freighters may be needed toward the end of the century, particularly for the international market. Long-lead research is already in progress and a major focused initiative in this area might be appropriate several years from now.

Cryogenic-Fuel Transports

Important system and economic questions can be resolved in this area through long-lead research and technology. Escalation of these activities to a major new focused initiative does not appear advisable in the very near term.

Rotorcraft

A rapidly expanding market has stimulated aggressive competition among the world's helicopter manufacturers. Acceleration of advanced technology development in the near term would play an important role in the outcome of future competition.

Commuter Transports

At the present time, it is not clear to what degree technology advances will influence commuter transport developments. Studies now under way will provide insight into the nature, scope, and timing of new focused technology initiatives.

General Aviation

General Aviation is characterized by a large and rapidly growing market. An expanded, broadly-based research and technology program may be warranted to provide a better technical foundation for subsequent commercial development as well as enhancements in safety, fuel consumption, service and environmental protection.

In addition to the seven vehicle areas discussed above, important opportunities exist for potential expansion in three fundamental technology areas--propulsion, aviation safety, and avionics and human factors--in which new initiatives could contribute both broadly and specifically to improvement and increased productivity in all vehicle classes.

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1. INTRODUCTION

The House of Representatives Committee on Science and Technology, in its Report No. 96-52, "Authorizing Appropriations to the National Aeronautics and Space Administration" (Ref. 1), raised several questions regarding future directions in NASA's Aeronautics activities. Specifically, the Committee noted with considerable alarm that NASA's Fiscal Year 1980 budget projections showed a decline in spending for aeronautical Research and Technology in Fiscal Years 1981 and 1982. The Committee expressed the belief that "the time is ripe for a bold new initiative in aeronautics, along the lines of the highly successful Aircraft Energy Efficiency Program." It suggested that this effort should be directed at advanced technology to increase productivity in air transportation, and should lead to exportable products to improve this Nation's balance of trade. The Committee requested that NASA prepare a "white paper" detailing program options along with cost and schedule information. This paper has been prepared in response to the Committee's request.

The Committee's report expressed concern as to the decline of U.S. transport aircraft dominance and stressed the importance of the relationship between research and development investments and the consequent benefits to the U.S. of preeminence in the civil aviation market. NASA shares the Committee's concern regarding the challenge of foreign competition and agrees fully as to the relevance and importance of research and technology.

The U.S. civil aircraft and airline industry is critical to the U.S. economy. In 1978, for example, it contributed $43 billion to the gross national product and provided approximately a million jobs. Civil Aircraft exports, primarily subsonic transports, produced a favorable trade balance of $5.6 billion--the highest positive component of this important measure of national well-being by any U.S. manufacturing industry.

The successful introduction of the Airbus Industrie's A300 has shown the reality of the threat to the U.S. aircraft industry from foreign competition. This threat is not limited to wide-body aircraft used in commercial transportation, although that market segment accounts for the largest sales volume. Serious competition also exists in the short-haul, utility, general aviation, and military aircraft categories. The magnitude of the world helicopter market potential, for example, has stimulated aggressive competition among the world's helicopter manufacturers. The foreign activity is characterized by high-quality technical products and, in some instances, strong government support to industry.

This international competition, already serious, will become increasingly intense as the market and its potential trade-balance consequences grow. With much of the transport market in the form of sales to international airlines, some aircraft programs may be based on production partnerships among multinational manufacturers. Even in such instances, however, the stakes will be great and competition for roles and shares within the partnership may be as heated as competition in the past between individual companies.

The scheduled air travel market, excluding the USSR and China, has now exceeded 400 billion passenger-miles per year. Representative projections indicate that this market will quadruple by the year 2000 or shortly thereafter. To meet this increase in the market, the sales of commercial aircraft will rise. The U.S. share of these sales recently fell to a low point of 77 percent of aircraft delivered in 1977 compared to 93 percent in 1974. While sales of transports to U.S. airlines are forecast to increase, these sales are expected to become a smaller fraction of the total free-world expanding market. Although it is unreasonable to expect that the U.S. aircraft industry could maintain indefinitely the near-monopoly it enjoyed through the early 1970's, the maintenance of a large market share assuring substantial growth in absolute sales is not only a realistic goal, but a national need.

A key to the challenge of foreign competition is the innovative application of advanced technology to achieve significantly improved aircraft with higher reliability, reduced cost of ownership, increased operational capability, decreased fuel use, and increased productivity. The application of advanced technology to the design, development, and manufacture of aeronautical products is the responsibility of the aeronautical industry. It is preceded, however, by a sequential research and technology process of generating new technical concepts, bringing them to maturity, assuring readiness for application, and facilitating the transfer of the technology to the private sector and to the Government agencies which procure, operate, or regulate aeronautical systems. NASA has the responsibility to provide this research and technology. It does so on the basis of in-house efforts and, where appropriate, work performed under contract by industrial organizations or universities.

In addition to its role related to civil aviation, NASA also has an important mission to support military R&D activities through basic, long-range, high-risk research which provides DOD with important advanced technology options for the future. The effort NASA devotes to military oriented long-range research greatly enhances the quality of NASA's overall aeronautics activity in that the high performance desired for future military capability presents a forcing challenge and motivation for accelerated advancement in all the basic technical disciplines which are critical to aeronautics, independent of specific application.

NASA's research and technology programs must be broadly based, with primary emphasis on new concepts and technical advances beyond the horizons of industrial, or military, development planners. The long-range orientation is intended to create advanced technology options for future societal benefits. NASA's programs must also assure adequate continuing attention to important public-interest research in which the private sector has neither the ability nor the motivation to invest substantially--for example, research to increase fundamental scientific knowledge or to establish the technical basis for regulations concerning environmental protection, safety, or energy conservation.

The U.S., the European countries, Japan and Canada have recently adopted an "agreement on trade in civil aircraft" as a result of the "Tokyo round" of the Multilateral Trade Negotiations. This agreement, enacted into law in the Trade Agreements Act of 1979, specifies in effect that the Signatory governments will not subsidize or protect their civil aircraft industries in such a way as to injure the industries of the other Signatories. NASA research and technology activities do not provide competitive advantage to an individual company, subsidize U.S. industry, or injure the industry of other countries, but serve to raise the general level of technology that will be available to the entire industry for the common good.

The current NASA Aeronautics program is the result of intensive planning and periodic assessments conducted by both in-house experts and external advisory groups. The advisory groups are drawn from the industry, Government, and university communities, and are consulted as to the content, balance, emphasis, and quality of the program. The result is a well-balanced program consisting of a broad R&T Base effort and a number of vehicle-class-oriented focused initiatives, including the major Aircraft Energy Efficiency (ACEE) program. The overall program also contains the seeds for potential new focused efforts for the future.

Slightly over 40 percent of the NASA FY 1979 Aeronautics R&D budget, and about 75 percent of the Aeronautics civil service direct manpower, are devoted to the R&T Base activity directed toward long-term state-of-the-art advances in the aeronautical disciplines. The remainder of the resources are primarily applied to the more near-term technology efforts, with a very small percentage used for systems studies to evaluate new concepts and identify potential technology benefits and requirements.

For major advances in vehicle-class-oriented efforts, particularly where societal benefits are important and the focused program entails high technical and economic risk, the technology preparation activities are extended by NASA beyond analysis and laboratory involvement to include feasibility demonstration and performance evaluation under realistic operational conditions.

These more-applied R&T activities reduce the obstacles to private-sector development and provide increased assurance that the benefits of the technology advances will be realized.

Under certain conditions, a number of applied technology projects may be grouped into a major focused initiative which becomes a large-scale activity such as the present ACEE program. Because focused initiatives are specific projects with finite life spans, they inevitably create peaks and valleys in funding requirements. The FY 1981-82 aeronautics funding reduction cited by the Committee is associated with ACEE program phasing. It in no way connotes a decline in NASA's dedication to research and technology directed toward improvement of the U.S. air transportation system and maintenance of military aircraft superiority. It does present possible opportunities to pursue other potential focused initiatives, several of which are discussed in this paper.

Large-scale initiatives such as the ACEE program can be effective in expediting the application of advanced technology when a number of factors such as a recognized need, a likely market, adequate research preparation, industry readiness and capability for development, and societal interest are all present at the same time. This was the situation that existed with respect to long-haul conventional subsonic transports at the time the ACEE program commenced. The appropriate timing for new large-scale focused initiatives in other areas depends on how rapidly the required combination of factors materializes for those areas.

The remainder of this paper contains an analysis of these factors with respect to potential initiatives in various segments of the civil aeronautics field, and outlines the corresponding program options which may be appropriate as additions to the presently planned NASA Aeronautics program, either in the near term or at a later date. These program options are presented as integrated total packages which apply large resources to the area in question. The program components can in most instances be treated also as incremental activities providing lesser but nevertheless effective progress toward the desired technology advances.

2. POTENTIAL NEW-INITIATIVE AREAS

In this section, specific aircraft types are considered in two classes: long haul (subsonic, supersonic, large cargo/logistic, and cryogenic-fuel transports) and short haul/utility (rotorcraft, commuter transports, and general aviation). For each of the aircraft types, which represent those from which candidates for appropriate focused initiatives are most likely to emerge, the discussion outlines the relevant market factors, the ability and readiness of the industry to undertake new development programs, and the technology factors which will influence decisions as to the timing of potential new major aeronautics initiatives.

2.1 LONG-HAUL AIRCRAFT

The long-haul civil aircraft market consists of current and future opportunities in subsonic transports, supersonic transports, large cargo/logistic aircraft, and cryogenic-fuel transports. Each of these elements is discussed from the standpoint of the market situation, the industry situation, and the technological factors involved.

2.1.1 Subsonic Transports

The market for new commercial air transports is undergoing a rapid expansion which financial analysts predict will peak probably between 1982 and 1984 at 550-700 aircraft deliveries per year (Refs. 2, 3, 4). This compares to a peak annual production of less than 250 aircraft and less than 3000 aircraft deliveries during the 1970's. Sales of commercial transports during the past 20 years exceeded 6200 aircraft (over $52 billion in current dollars). During the next twenty years, the entire existing fleet may be replaced. Over 5000 aircraft may be produced in the next decade and perhaps another 5000 in the decade ending in the year 2000. Figure 1 illustrates a major manufacturer's view of the historic and forecast levels of cumulative aircraft production (Ref. 5).

Two factors are driving this potentially dramatic growth of aircraft sales: (1) the need to replace existing aircraft, and (2) the growth in air travel demand. Over 2000 aircraft may be retired and need replacement by 1990 due to their age, noise, emissions, and fuel consumption characteristics. Air travel demand is also rising, creating a need for more available seats. Figure 2 portrays the historic and forecast levels of worldwide air travel in terms of revenue-passenger miles.

Historically, U.S. manufacturers have produced almost 90 percent of the commercial air transports, based upon a full array of aircraft sizes and mission characteristics, a large domestic market, and extensive sales abroad. In the future, the U.S. domestic air carriers will be purchasing a smaller portion of the world's new aircraft, due to more rapid growth of air traffic in other parts of the world and along international routes. This trend will diminish the relative marketing base of the U.S. airframe manufacturers. Today, the challenge from foreign manufacturers is strong and they are making serious inroads into what has been a U.S. near-monopoly. For instance, McDonnell Douglas' 1978 sales in the world air transport market fell to third place, behind the European Airbus consortium which captured 30 percent of the sales of wide-body jets. In moving into second place, the Airbus consortium tripled its market share to 19 percent. There will be increasing competition from foreign manufacturers in the future as they invest revenues from their current orders into the development of a full family of aircraft sizes for different markets and missions. This trend is already evident with the decision to build the smaller A310 derivative of the A300 and the announcement that Airbus intends to develop a four-engine, long-range A300 derivative and a 130-160 passenger, short/medium-range transport.

Multinational consortium arrangements such as Airbus Industries benefit from broadened market appeal as well as risk-sharing. Currently, the Airbus consortium's new orders for its existing A300 and A310 models exceed the combined new orders for the U.S.-made DC-10, L1011, and B767. Complaints have been voiced to the effect that some Airbus orders may have been influenced by considerations other than price or performance, such as lenient financing terms, subsidies, or various forms of political pressure. (Similar complaints have been voiced regarding sales of U.S. products.) The facts remain, however, that the A300/A310 aircraft are quality products incorporating highly competitive technology, and that they successfully fill important market gaps. The recently accepted international agreement on trade and civil aircraft is intended to prohibit unfair trade practices and eliminate tariff barriers, including the U.S. 5-percent tariff. In the highly competitive years ahead, adherence to the new trade agreement will place an even greater premium on an aircraft's technical and economic merits.

The general health of the U.S. air transport manufacturing industry is good, although limited resources and uncertainties concerning airline finances, fuel availability, the implications of a deregulated air carrier market, future environmental standards, and the effects of inflation have inhibited the development of major new aircraft designs. The recent evidence of airline intentions and capability to begin large-scale new fleet purchases has prompted the B757 and B767 developments and the planning of the B777 and several DC-10, L1011, and B747 derivatives. These designs generally incorporate modest evolutionary technology advances directed at fuel efficiency, noise reduction, and reduced operating costs.

Development of a new commercial aircraft is an extremely risky venture, with capital requirements often equivalent to or greater than the net worth of the manufacturer (Ref. 6). Aircraft investment and return cycles are quite lengthy. The development phase for a new aircraft can take many years. Extensive research, development engineering, and tooling costs are incurred before appreciable payments are received. Profits may not start to accrue to the manufacturer until there have been as many as ten years of deliveries involving at least 300-400 orders. Under such circumstances, managements are very circumspect before committing resources to a new venture or incorporating radical innovations and technology. Production runs of successful aircraft may span twenty years or more.

Despite many optimistic forecasts of airline traffic growth, there are still uncertainties as to whether air carrier earnings growth and financial resources will support the enormous aircraft sales that have been forecast (Ref. 7). In any event, it is highly unlikely that the air carriers now ordering substantial numbers of new aircraft or new derivatives will be ready for purchases of "newer-generation" aircraft in the near future.

Military developments in the past often resulted in aircraft which led to, or facilitated, related civil versions. One widely cited example is the relationship between the KC-135 tanker and the B707. Recently, however, the military have not been developing transport-type aircraft that could serve to facilitate civilian offshoots. The Air Force adaptation of the DC-10 as its new tanker/cargo aircraft, the B707 for AWACS, and the B747 for the Airborne Command Post appear to support the belief that military programs will not spur accelerated development of new long-haul civil air passenger transports.

The above discussion leads one to conclude that the introduction of a completely new long-haul subsonic transport during the 1980's has been largely preempted by the decision to produce the B757 and B767 during the early 1980's, and by plans for the B777 and for DC-10, B747, L1011, and Airbus derivatives. These aircraft will incorporate some of the technology that has been developed as part of the ACEE program. Additional technology developed in the ACEE program will be available for incorporation in subsequent derivatives of these aircraft and in new designs for the period beyond the 1980's, as will further advances in safety, terminal operations capability, navigation and control, environmental acceptability, engine performance and more extensive use of composite materials. These advances will depend on expanded research and technology efforts which, as outlined in Section 3.1, could take place both in parallel with and subsequent to the ACEE program. At this time, however, it does not appear that a major new ACEE-type focused initiative is required for the further development of subsonic transports in the near future.

2.1.2 Supersonic Transports

In the 1960's, the governments of Great Britain, France, the Soviet Union, and the U.S. were pursuing technology and prototype programs in support of potential supersonic transport developments. In 1971, the U.S. project was abandoned. The British/French Concorde program continued and the aircraft is now in regular commercial service. Several versions of the Soviet TU-144 have been utilized in extensive test programs and these activities are continuing.

The market and industry factors discussed in Section 2.1.1 are generally applicable to supersonic as well as subsonic transports, and suggest that development of a new supersonic transport before 1990 would be rather unlikely. However, there are strong indications that as the air transportation demand growth continues, and particularly as expanded trade with Asia, Africa, and South America creates increased traffic in the longer-distance, time-consuming over-ocean routes, an important market for a second-generation SST will materialize at a later date.

Projections to the year 2000 indicate a market for several hundred SST's--a large enough number for an economically successful single venture, but not large enough to clearly assure success for two competing programs. Although the projected production quantity is appreciably smaller than those of most of the successful subsonic transport programs, the dollar value of the SST program takes on greater significance because of the higher unit aircraft cost, possibly on the order of three times that of the larger subsonic aircraft. Of equal importance, however, is the anticipated impact of SST sales on the sales of long-haul subsonic aircraft. Because of their higher productivity, second-generation supersonic transports could replace approximately twice the equivalent number of subsonic transports. In short, a successful new supersonic transport program in which U.S. manufacturers did not play a major part would be injurious to the country's aeronautical industry and its economy.

To satisfactorily fill the market need, the new aircraft would have to show considerable improvements with respect to the shortcomings which led to the cancellation of the previous U.S. SST effort and which have limited Concorde's commercial acceptance. The required improvements include meeting current FAR-36 noise standards, satisfying pollutant emission standards both in the airport vicinity and at altitude, carrying considerably higher passenger payloads over transpacific ranges (4200-4800 nautical miles) at ticket prices lower than the equivalent of current first class fares, and achieving perhaps a 50 percent reduction in direct operating cost. The aircraft would also have to operate reasonably efficiently at subsonic speeds for flight over populated land areas or during engine-out situations.

In view of the benefits of Concorde operational and test experience, and the additional advantage of 20 more years of research and technology progress, there is a high probability that a second-generation SST incorporating the necessary improvements could be developed. The U.S. manufacturers, of course, are not benefitting directly from the Concorde or TU-144 experience. They are, however, involved in the ongoing supersonic cruise research which NASA has been conducting to maintain the options for eventual U.S. supersonic transport development decisions.

As a result of the NASA and industry programs, the advanced technology elements essential to the development of an economically successful second-generation supersonic transport have been identified. The efforts required for technology validation and technology readiness have been described in two NASA reports to the House of Representatives Committee on Science and Technology (Refs. 8, 9) and are discussed further in Section 3.2.

Assuming the necessary technology can be brought to a state of readiness which would make possible sufficiently low-risk development, the question of development cost and financing must still be addressed. The cost of developing a totally new supersonic transport meeting all of the requirements outlined above has been estimated at 6-10 billion dollars. It is highly unlikely that any one manufacturer would be capable of undertaking such an effort in the foreseeable future, and it is not even clear that a commercial consortium development would be feasible. A less ambitious advance, particularly if derived from Concorde, could be developed at less cost and in less time, but might not be as successful a product economically.

The decision to progress from the present supersonic cruise research level of activity to a large focused initiative directed at technology validation or technology readiness is major, important, and complex. To proceed with so large a step without first having resolved the development financing issue would be an expensive form of insurance, although it might be a desirable course if taken consciously. On the other hand, excessive delay in the long lead technology preparation process could be tantamount to losing by default a key component of future world leadership in transport aircraft.

The Office of Technology Assessment (OTA) is currently conducting for the Congress a study of advanced air transport technology, including consideration of supersonic transports and their economic implications. This study may produce information which will facilitate the necessary national policy decisions. The program options discussed in Section 3.2 include progression from the present research level of activity to a technology validation program.

2.1.3 Large Cargo/Logistic Aircraft

Air freight provides an important and growing service, and a potential market for new transport aircraft. Cargo traffic in 1978 amounted to 8 billion ton-miles for domestic U.S. operations and 21.6 billion ton-miles worldwide excluding the USSR and China. Despite these impressive figures, the air mode amounts to considerably less than 1 percent of the entire freight market. Air cargo rates, including pickup and delivery charges, are generally 2 to 4 times higher than surface rates, and air freight typically takes the form of small, high-density shipments being transported by air because of urgency, high value, security, or perishability. If the air mode's penetration of the freight market does not increase markedly beyond its present small share, the projected growth can be accommodated for many years by the use of belly cargo compartments, and freighter or "combi" versions, of passenger transports. If air cargo achieves an appreciably greater penetration, the independent development of dedicated freighters may be warranted.

System studies have indicated that air transportation could attract a much larger fraction of the cargo market if major improvements in service, and/or significant cost reductions, were offered. The desired improvements are only partially associated with aircraft characteristics. Some important advances could be achieved in new specialized air freighter designs--for instance, large cargo aircraft with payloads much greater than those of the B747F or C-5A with reduced ton-mile operating costs, and aircraft sufficiently quiet to permit unconstrained night operations at major terminals. The development of such aircraft will require new technology beyond that being generated for passenger transports, and will be justified economically only when the accelerated market growth actually begins to materialize.

For perhaps the next decade, it appears that the most fruitful efforts to stimulate air cargo growth would be those focused on the improvement of service utilizing aircraft now in operation or being developed. Improvements, for example, in cargo handling and transfer, intermodal containers, systems management, rate rationalization and simplification, marketing, and scheduling--all directed at assuring convenient, economical, and dependable door-to-door service--would be important steps in creating an air cargo market strong enough to warrant the development of advanced freighters. The advanced freighters would offer still greater improvements in cargo service and economy and would constitute a potentially important product in the world-wide competition for aircraft sales.

NASA studies suggest that new-technology dedicated freighters may be needed toward the end of the century, particularly for the international market. As discussed in Section 3.3, related long-lead research is already in progress, and a major focused initiative in this area might be appropriate several years from now. The necessity for increased emphasis on large cargo aircraft technology would be increased if a high national priority were assigned to a military requirement for improved logistic support capability. Although commercial and military requirements diverge in several important aspects, there is high commonality in many technology areas, and studies are being conducted to determine the extent to which common development of a large cargo aircraft might be feasible.

Another factor which could influence the timing of a major focused initiative in this area is the OTA study of advanced air transport technology mentioned in Section 2.1.2, which includes consideration of advanced large dedicated cargo aircraft.

2.1.4 Cryogenic-Fuel Transports

Civil air transportation currently accounts for about 2 percent of the total U.S. energy consumption and about 4 percent of the petroleum energy consumed. Current research programs are generating technology for major improvements in aircraft energy efficiency. The question of future aviation fuel consumption remains an important concern, however, because of the large projected growth in air transportation and the uncertainties regarding fuel availability and price.

As the higher grades of crude oil become more scarce and the demand increases, there will be intense competition among users for the mid-distillate fraction of the crude. Aviation will be in competition directly with industries using turbo-generators and diesel engines, and indirectly with fuel-oil consumers. As shown in Figure 3, the normal service life of the next new commercial transport will span the predicted peak and significant decline of worldwide crude oil production.

NASA's ongoing and planned propulsion research activity includes serious emphasis on broadening fuel specifications in the interest of greater fuel availability and reduced refining cost, and on assuring the feasibility of civil aircraft use of synthetic aviation kerosene derived from noncrude sources such as shale or coal. These efforts should continue, but are not likely to require a major focused initiative in the context of the Committee request.

The possibility of a more drastic departure in fuel types to be used in civil aircraft does exist, however, and this may eventually require a major focused research and technology initiative. Liquid hydrogen (LH_2) and liquid methane (LCH_4) may become attractive as possible aircraft fuel alternatives because of their high energy content per pound and their potential environmental advantages, and because they may be derived not only from coal but from renewable energy sources as well. Preliminary flight testing conducted by the NACA in 1957 and more recent studies have shown that the use of these cryogenic fuels on large aircraft would be feasible. Several critical technology needs have been identified, particularly with respect to the insulation and structure for the large cryogenic fuel tanks and the pumping equipment for delivery of fuel to the engines.

Although the aircraft technology problems will require considerable time and resources to resolve, the decision to proceed with a major focused initiative on cryogenic-fuel transports is influenced by several other long-lead considerations which may be more fundamental. A number of processes for the manufacture and liquefaction of hydrogen and methane have been examined from the standpoint of feasibility, cost, and energy consumed in production. These studies did not resolve the fuel price question, and it was concluded that the price picture would not be clear until plants are constructed and fuels are actually produced (Ref. 10). It is doubtful that the prospect of use on transport aircraft would, in itself, provide sufficient motivation for establishing large-scale production and distribution facilities for cryogenic fuels in the near future. When more widespread use of these fuels is foreseen for other purposes, the aircraft application will become more viable.

In addition to the questions of initial manufacture and price, aircraft use of cryogenic fuels will require costly ground facilities at each air terminal selected for operation. It has been estimated, for example, that the necessary liquefaction, storage, and distribution facilities for San Francisco and O'Hare international airports alone would cost approximately $340 million and $470 million respectively (Ref. 11).

Some of the long-lead research and technology necessary in support of future aircraft use of cryogenic fuels can be accomplished prior to the resolution of the related system and economic questions. These questions should, however, be addressed before a large-scale commitment of resources, and escalation of the research to a major new focused initiative therefore does not appear advisable in the very near term.

2.2 SHORT-HAUL/UTILITY AIRCRAFT

Short-haul and utility aircraft provide a variety of essential services and constitute a multi-billion dollar annual market of growing national and international importance. Included in this category are rotorcraft, commuter transports, and general aviation aircraft, each of which is discussed separately in this section.

2.2.1 Rotorcraft

The growth of the rotary-wing sector of aviation has generally lagged that of conventional fixed-wing aircraft by 20 to 30 years. After the difficult initial achievement of controlled vertical flight, helicopters evolved primarily through experimentation with modest incremental departures from proven designs. They became valuable despite technical and economic shortcomings because of their unique capability to perform specialized tasks. In recent years, industry and Government R&D has resulted in significant improvements, and rotorcraft have been recognized as potentially valuable for use in an increasing number of military and civil applications in which the rotorcraft's cost-effectiveness is important as well as its unique capability.

The recognition of greatly improved utility has led to projections of large and rapid growth in the rotorcraft market and these have stimulated aggressive competition among the world's helicopter manufacturers. The U.S. position as the free-world leader in this field is being effectively challenged by foreign designers. Successful response to this challenge requires the innovative application of advanced technology to achieve appreciably improved vehicles with higher reliability, reduced cost of ownership, and increased operational capability.

Business rotorcraft represent a growing factor in air transportation, with particular attractiveness at distances between approximately 50 and 200 miles and in situations in which the value of travelers' time is important. Executive transportation by helicopter has been growing at a rate in excess of 20 percent. With increased cruise speeds, the helicopter will be competitive with fixed-wing aircraft at even longer ranges, and the business and air-taxi markets should expand even more rapidly. Scheduled helicopter service is likely to grow, particularly as increasing air transportation demand leads to serious congestion at major hubs, but will depend largely on the realization of major cost reductions through new technology applied to large rotorcraft of 100-200 passenger capacity.

Helicopters have in recent years made substantial contributions to forest management including disease protection and seeding, forest firefighting, and timber harvesting in inaccessible areas. Although they comprise only 10 percent of the total agricultural aircraft fleet, helicopters are estimated to accomplish 20 percent of the agricultural work because of the increased productivity resulting from their greater maneuverability and their ability to refuel and reload on site.

Helicopters have become a vital tool in the search for, and production of, essential natural resources--particularly in remote coal or oil fields and in off-shore oil operations. They now provide transportation for some 230,000 passengers each month in the Gulf of Mexico alone, and over 80,000 in the new North Sea operations. Worldwide totals in excess of one million passengers a month are projected by 1985, with average stage lengths doubling to 200 nautical miles. With the introduction of larger helicopters, movements of heavy cranes and other equipment as well as people are anticipated.

Similar examples of rotorcraft demand growth are found in mining (e.g., a 14-fold increase in mining companies employing helicopters from 1974 to 1977), construction, public service (rescue, police, and emergency ambulance missions), and short-haul cargo movement. In short, tremendous growth in worldwide helicopter fleets, and fierce worldwide competition for the rotorcraft market, may be expected to occur in the 1980's and 1990's. Growth rates in recent helicopter sales have been more than twice those of conventional transports.

In the past, U.S. manufacturers have captured over 80 percent of the free-world market sales. This figure is expected to drop to slightly over 60 percent in the early 1980's. Four major European companies (Aerospatiale, Westland, Agusta, and Messerschmitt-Boelkow-Blohm) have now joined the four major U.S. companies as developers and large-volume producers of new helicopters, and companies in 16 additional countries now have, or will soon have, production capability through license agreements. In view of the larger number of competitors, the more diverse nature of potential customers, and the lower cost of new developments, the rotorcraft market represents more of a "free-for-all" situation than, for example, the competition for long-haul subsonic transport sales in the near future. U.S. manufacturers have ample motivation and financial capability to compete in this market, but will be hard pressed to maintain a competitive edge for designing technically superior vehicles with increased reliability, economy, and operational capability. An acceleration of advanced technology development by NASA would play an important role in the outcome of this future competition.

2.2.2 Commuter Transports

The commuter air carrier segment of U.S. air transportation was established by the Civil Aeronautics Board in 1969 to ensure service to small communities. This low-density service had proven an economic burden first to the trunk airlines and then to the local service airlines as they grew and upgraded their fleets with larger aircraft.

Scheduled commuter airline service in the U.S. has grown from 4.2 million passengers and 38.7 million pounds of cargo carried in 1970 to 9.2 million passengers and over 320 million pounds of cargo carried in Fiscal Year 1978. U.S. commuter airlines now operate at over 800 airports, approximately half of which are totally dependent on the commuters for their air service. Although characteristics vary widely among the large number of commuter airlines (260 in 1978), commuter service generally involves connecting outlying communities with a major city or airline hub, at distances ranging typically from under 50 miles to slightly over 200 miles. The amounts of passengers, cargo, and mail boarded at most of the airports served are quite small and small transport aircraft are needed for economical frequent service.

FAA forecasts project continuing commuter growth, with 16.5 million passengers expected in 1990 for a total of over 2 billion revenue passenger miles--an increase of 163 percent relative to 1978. This growth has been estimated to create a need for more than 250 additional aircraft in the 20-39 seat category for the top 50 U.S. commuter airlines alone, and a minimum worldwide market for more than twice that many. Other forecasts for the years 1980-2000 suggest a total world market for small transport aircraft in the thousands for each of three size classes (15-19 passengers, 20-39 passengers, and 40-60 passengers), with significant numbers needed in many of the developing countries.

The U.S.-built aircraft currently used by commuter airlines are principally derivatives of general aviation aircraft and were not initially designed to withstand the high utilization rates demanded in scheduled transport operations. At present, there is only one current-technology small transport--the 19 passenger, Swearingen Metro--being produced in the U.S. to satisfy the commuter needs for transport aircraft in the 15-60 passenger capacity range, although Beech recently announced plans to produce an improved version of the Beech 99 and three other models. Transports in the desired size classes are being produced, and sold, by manufacturers in Canada, Northern Ireland, the Netherlands and Brazil. and future designs are being studied in these countries and in France, West Germany and Italy as well.

At the present time, it is not clear to what degree technology advances will influence future commuter transport developments. Although needs for improvement have been identified in major technical disciplines, it has thus far been difficult to define research directed toward these improvements which is truly unique relative to the research needs of general aviation or conventional transports. It has also been difficult to assess the relative merits of technology advancement and design simplicity as means of achieving the cost reductions required for attractive competitive commuter transports in the 15-60 passenger size class.

NASA has undertaken contracted studies with U.S. airframe and engine manufacturers to determine the benefits that candidate advanced technologies offer to small, short-haul transports for the commuters. One of the goals of these studies is to identify those advanced technologies which should be considered for future research, and to establish the scope and schedules necessary to achieve timely technology readiness.

These studies and the OTA study, which is also addressing low density air service, will provide important insight as to the nature, scope, and timing of focused technology initiatives directed at the improvement of commuter transport aircraft.

2.2.3 General Aviation

General Aviation (G.A.) consists of all civil aviation aircraft and operations other than those of certificated airlines, commuter airlines, and contract carriers. Comprising over 98 percent of all civil aircraft, G.A. consists of many aircraft types and sizes ranging from corporate multi-engine jet aircraft to small home-builts. This diversity represents a correspondingly broad spectrum of uses, including business transportation, air taxi and utility, agricultural and industrial operations, public service, personal transportation, training and recreation.

The dominant use of G.A. is by business and industry, and this year more than 76 percent of the 41 million G.A. hours flown in the U.S. should serve these purposes. Notwithstanding this fact, the image of G.A. as sport flying has not been replaced in the public consciousness by full recognition of G.A.'s far greater role. The significant growth of G.A. in the U.S. and world wide testifies to increasing acceptance of general aviation's capability to provide services which other modes of transportation cannot provide as easily, conveniently, economically, or sometimes at all. By the end of 1979, there will be approximately 200,000 G.A. aircraft in the U.S., or about 62 percent of the world's civil aircraft fleet. It is estimated that by 1990 the U.S. fleet should be nearly 310,000 aircraft, with worldwide fleet numbers somewhat larger proportionately.

General aviation annual shipments and factory net billings by U.S. industry have grown steadily during the 1970's. Shipments and billings in 1979 should be more than 18,000 units and $2.1 billion, compared to 7464 units and $313 million in 1971 (Ref. 12). U.S. manufacturers have traditionally provided more than 90 percent of the world's G.A. aircraft, and sizeable fractions of annual deliveries are to foreign markets. Exports have grown from 1845 units worth $96 million in 1971 to an estimated 3700 units worth $500 million in 1979.

These statistics and growth projections highlight the present healthy state of general aviation and its manufacturing industry in the U.S. Despite this, however, several negative factors have emerged which could truncate growth and harm the industry if not remedied. Chief among these factors are:

- decreasing availability of aviation gasoline
- increasing fuel costs
- growing pressures to reduce airport environmental noise
- growing traffic congestion at major airports
- increasing concern over the compatibility of G.A. with the air traffic control system, enroute and in the terminal area
- increasing concern over G.A. safety issues
- increasing worldwide manufacturing and sales competition

While the underlying conditions which have caused these problems and challenges may be inevitable consequences of G.A.'s success and the resulting increase in numbers of aircraft and operations, further technological advancements should be able to minimize or even circumvent their undesirable consequences on the future of G.A. The opportunities for improvement include: more fuel-efficient aircraft and engines; more fuel-conservative operations; improvements in propeller aerodynamics and structural efficiency; aircraft drag and weight reduction; increased stall/spin safety; greater protection of occupants in the event of accidents; and major advances in improved and affordable avionics systems for navigation, control, and flight management. Significant opportunities also exist for increased utility of General Aviation aircraft, such as the improvement of aerial applications technology for agricultural and related activities.

Worldwide competition for the U. S. General Aviation industry is a clear challenge, and perhaps a threat to its future economic health. G.A. exports are already an important contribution to our balance of payments, and the expected future market growth will further increase their importance to the U.S. economy. The key issue is whether advanced research will be accomplished in the U.S. to provide the basic foundation for needed design improvements and innovations. Historically, the G.A. industry has not had the staff, facilities and financial resources to conduct its own long-lead research, spending less than 5 percent of its gross sales on product engineering which included almost no advanced research. In contrast, commercial transport manufacturers spend up to 20 percent of their gross sales on engineering geared to developing a higher technology product line (Ref. 13). Neither segment of the industry has adequate resources to conduct all of the necessary precursor research and technology. For many years, the G.A. industry has relied heavily on technology derived from Government programs such as NASA's, and from characteristically higher-technology sectors of aviation. More recently, there has been a divergence of technology application between G.A. and the military and transport aircraft fields, making technology transfer to G.A. more difficult. Because of these factors, an expanded, broadly-based NASA research and technology program aimed specifically at the unique needs and opportunities in General Aviation may be warranted not only to make available a better technical foundation for subsequent commercial development, but also to provide for important public benefits such as improved safety, reduced fuel consumption, greater utility and service, and environmental protection.

3. PROGRAM OPTIONS

The foregoing discussions suggest that potentially important major new focused initiatives exist in a variety of civil aeronautics categories. Some of the candidate programs are larger than others and some appear more appropriate than others for implementation in the very near future.

In general, considerable uncertainty exists as to the desirability of major new initiatives related to long-haul air transportation in the immediate future. The technical content of significant activities for subsonic and supersonic transports and exploratory focused efforts on large cargo/logistic aircraft and cryogenic-fuel transports are presented in this Section. The major unanswered question at this time is the appropriate timing for the initiation of such options. The potential importance of such initiatives dictates that effective research preparation continue so that the transition to these more focused efforts can be effected without delay when the timing becomes appropriate. In the short-haul/utility area, early expanded activity appears appropriate with respect to rotorcraft and general aviation, and continued study to determine requirements for new technology applicable to commuter transports appears necessary.

In addition to potential focused initiatives for specific vehicle classes, there are several areas of fundamental technology which require intensive concentrated efforts because of their generic importance to all of the vehicle classes. The accomplishment of these necessary concentrated technology efforts may warrant focused activities similar to those required in the vehicle-class initiatives.

The potential focused efforts in each of the identified need areas--seven vehicle classes and three fundamental technologies--are outlined in this Section. Relative priorities, program start dates, and overall program balance have not been addressed and are the subject of continuing planning studies.

3.1 SUBSONIC TRANSPORTS

For the near term, it appears that industry emphasis will be on the B757 and B767 as well as derivatives of current aircraft (e.g., the DC-10, L1011, B747) incorporating evolutionary refinements which will result in quieter, more fuel-efficient, lower maintenance subsonic transports compatible with expected higher air traffic densities. For the longer term, in addition to further derivative aircraft, the potential exists for an era of new aircraft designs and concepts. Technology developments beyond those currently planned could provide advancements with which industry designers and airline operators could further improve subsonic transports to counter the increasing competition from foreign manufacturers in the world market and help prevent the occurrence of terminal area congestion.

3.1.1 Technology Needs

The primary opportunities for near-term applications of technology in subsonic transports involve engine component upgrading, the introduction of improved structural materials in non-critical components, modifications for better aerodynamic efficiency, and the reduction to practice of improved terminal area operational techniques. For each aircraft or engine modification, the industry would adopt those technology advances which offer a satisfactory level of benefit at an acceptable risk.

For the generation of new transports which could be designed in the period beyond the 1980's, the opportunity would be available for the introduction of major advances in transport technology with emphasis on energy efficiency through advanced engines, structures, aerodynamics, avionics and control. Emphasis would also continue on environmental compatibility, safety and terminal-area operations. The technology must be developed for integration of these specific advancements into transports which exhibit higher productivity, lower operating costs, lower acquisition costs, and compatibility with the future air traffic control system.

3.1.2 Ongoing Research

The major thrust of the current NASA long-haul subsonic transport research effort is the multi-disciplinary Aircraft Energy Efficiency program. The program features focused activities in aerodynamics, structures and materials, propulsion and controls. This initiative has six major elements:

- engine component improvement
- energy efficient engine
- advanced turboprop
- energy efficiency transport
- laminar flow control
- composite primary aircraft structures

The Engine Component Improvement program consists of two major activities--engine performance improvement and engine diagnostics, aimed at reducing fuel consumption in current engines by at least 5 percent. The screening and detailed evaluation of promising component modification concepts for the JT8D, JT9D, and CF6 engines have been completed for the engine performance activity. Many of the advanced components evaluated are incorporated in the new derivative engines currently being offered by the manufacturers. The engine diagnostics activity has principally focused on the collection and evaluation of performance deterioration data on current high-bypass-ratio turbofan engines. A better understanding of the deterioration mechanisms has led to adjustments in maintenance procedures and design practices to improve performance retention in current and future engines.

The objective of the Energy Efficient Engine program is to develop and demonstrate the technology for a new generation of energy-efficient turbofan engines. The goals are to reduce specific fuel consumption by at least 12 percent and improve direct operating costs by at least 5 percent relative to current high-bypass-ratio engines, while simultaneously reducing noise and emission levels.

The Advanced Turboprop program is aimed at developing technology for efficient, reliable, and environmentally acceptable high-speed turboprop propulsion systems for future commercial transport aircraft. The goals are to reduce fuel consumption by 15 to 20 percent and direct operating costs by at least 5 percent relative to turbofan engines with equivalent technology.

The Energy Efficient Transport program focuses on advanced aerodynamics and active controls technology for application to derivative and new transport aircraft. Activities include research on wing tip extensions and winglets, lower drag nacelles, reduced horizontal tail size, and reliable fault-tolerant computers.

Laminar Flow Control offers the potential of providing fuel savings of from 20 to 40 percent through reductions in aircraft drag as a result of maintaining smooth or laminar flow over the wings and empennage. A suction system would be used to remove low-energy air near the surface and thereby control the boundary-layer flow characteristics. The Laminar Flow Control program is aimed at the development of a practical, reliable, and maintainable system for boundary-layer control.

The Composite Primary Aircraft Structures program has the objective of accelerating the introduction of composite structures in commercial transport aircraft. The program includes the development of three secondary and three medium-sized primary components to validate structural and fabrication technology and to obtain component experience in airline applications.

Another major part of the long-haul subsonic transport research and technology effort is the Terminal Configured Vehicle (TCV) program, an advanced integrated systems technology activity focused on improved operations of conventional takeoff and landing aircraft in high density terminal areas with reduced weather minima. The purpose of the program is to address the improvement of airborne equipment and procedures in future high density terminal areas, considering advanced flight systems (primarily controls and displays) coupled with improved navigation, communication, and landing guidance. Part of this program is to assess the impact and interaction of these improvements with the air traffic system; thus, TCV is a cooperative endeavor with the FAA and airline users.

3.1.3 Program

The objective of an expanded research and technology program on subsonic transports would be to provide the basis for a future generation of advanced technology transports which could be designed and developed in the period beyond the 1980's. The overall content of the program can be grouped into five areas:

1. Advanced TCV Technology - an augmentation to the TCV program, utilizing more advanced avionics and aircraft systems, which would continue as a cooperative effort with the FAA.

2. Advanced Commercial Engine Technology - an aggressive propulsion technology development and validation effort beyond the Energy Efficient Engine program.

3. Active Controls Technology for Transports - a demonstration of technology readiness.

4. Avionics and Controls Integration - extending ACEE program efforts to include an in-service demonstration.

5. Large Composite Primary Aircraft Structures - an effort to demonstrate composites technology readiness in major structures such as the wing and fuselage.

The schedule and funding for this program is shown in Figure 4 for each of its elements.

Advanced TCV Technology

The objective of this effort would be to accelerate the determination and validation by flight tests in an airline operational environment of the optimum instrumentation and flight control concepts for manual and automatic operation of conventional and wide-body aircraft in a high density traffic environment.

This program would encompass automatic/optimized cockpit activities, enhanced pilot/controller interactions, more precise position fixing, adverse weather take-off and landing, improved weather information, severe windshear capability, optimal energy management, system fault-tolerance and reconfiguration, sophisticated self-test capability, climbout and descent profiles, high-speed runway turnoff capability, and accommodation of advanced Air Traffic Control (ATC) concepts and procedures. The technical approach would include:

- industry studies of airborne system options for improving productivity and equipment simplification;

- upgrading the TCV B737 aircraft and simulation facilities to incorporate improved displays, control, guidance and navigation systems for conduct of interactive experiments consistent with 1990 ATC system concepts;

- establishment of performance and operating limits and definitions of hardware, crew and ground interface requirements;

- integration of advanced technology cockpit displays, controls and avionics into a wide-body transport aircraft;

- on-line demonstrations during normal scheduled widebody aircraft operations to establish confidence in the system; and

- analysis of results to verify compatibility of interfaces, functions, crew roles and procedures, providing data on which to base decisions for proceeding with advanced system implementation.

The above tasks would be accomplished over a period of eight years. This time span is necessary in view of the complexity of the program. Program completion would occur as implementation of the continually upgraded air traffic control system takes place, and would assure a technology base for airborne systems and flight procedures which would enable full compatibility of advanced technology transports with the National Aviation System of the 1990's.

Advanced Commercial Engine Technology (ACET)

The overall objective of this effort would be to develop and investigate, on a continuing basis, selected advanced component and engine system technologies for future economical and environmentally acceptable subsonic transport engines. It would serve as a focus for the various component R&T Base fundamental technologies by providing a continuing process of investigation and evaluation in a realistic environment. It would also seek to maintain a state of technology readiness to assure continual availability of proven advanced engine components that meet the severe environmental and performance demands of the future.

The ACET program would be structured into two phases of five and six year duration and would develop engine component technologies at progressively higher levels of advancement relative to the Energy Efficient Engine (EEE) program.

Phase I would begin with the selection of component technologies emerging from R&T Base programs which exhibit potential benefits in fuel efficiency, operating costs, performance retention, emissions, and noise. The technologies would be investigated by means of component rig tests, followed by incorporation into the advanced EEE core and integrated core low spool systems testbeds for further evaluation and final verification. Candidate Phase I components include a high-pressure turbine, broad-specification fuel, low-emission combustor and a closed-loop, modulated, active clearance control system for improved performance retention.

Phase II would extend the level of component technology further than Phase I by increasing the pressure and temperature levels beyond the conditions in the current EEE program. Higher performance compression systems with minimum stages would be evaluated along with high work, second generation, single-stage turbines. Feasibility and preliminary design studies would be conducted to assess the potential of emerging R&T Base technologies. Component rig tests would be conducted, followed by investigations and evaluations at integrated systems levels.

Active Controls Technology for Transports

The objective of this effort would be to provide the aircraft industry with the confidence required for application of Active Controls Technology (ACT) to a first-generation control-configured transport. Incorporation of ACT concepts early in the design cycle can provide the designer with more flexibility in making trades leading to the "best" configuration. Potentially sizeable reductions in fuel use due to reduced aircraft weight and drag may be possible. Operational data are needed, particularly systems experience under conditions of routine airline service and maintenance.

This program would consist of feasibility and design studies; hardware and software fabrication, development, and laboratory evaluation; and an in-service demonstration of an ACT system retrofitted to a contemporary transport aircraft which would provide a means for accumulating a real-world operational data base. The tasks would be divided into two phases. Phase I would commence with feasibility studies of advanced avionics and controls technology in addition to the Energy Efficient Transport active controls systems concepts and the selection of specific concepts for detailed design, fabrication, ground test, and laboratory simulations.

In Phase II, the control systems of one or more contemporary subsonic transports would be selected for redesign with active controls. A number of aircraft would be retrofitted. Operating airlines would obtain supplementary type certificates for the aircraft and would provide routine service and maintenance of the ACT systems during flight operations to accumulate a statistical data base.

The overall program duration would be eight years. The decision concerning the in-service demonstration would be made during the third year of the program, and the flight experience accumulation and demonstrations would occur over the final four years. The Phase I laboratory tests would continue in parallel as a support function to the flight experiments.

Avionics and Controls Integration

This activity would develop and demonstrate integrated avionics and control systems technology for commercial transport applications in the period beyond the 1980's. The opportunity exists for sizeable benefits to accrue through systematic integrated design of transport avionics and control systems. Power and weight savings are possible, together with increased reliability and reduced maintenance through a reduction in the number of system elements. In addition, added flexibility could be provided for effecting changes in mission-related avionics and controls functions and capabilities. An experience data base from the evaluation of potential integrated avionics and control systems is needed before these types of systems can be incorporated in future transport aircraft designs.

The program would consist of two phases. Phase I would include systems integration functional requirements studies, architectural concepts definition, and criteria formulation for the selection of a test aircraft for a subsequent flight evaluation and demonstration phase. Phase II would include design, procurement, and laboratory evaluation, including simulation, of those avionics and control systems which have been integrated. A subsonic transport would be selected for modification through the installation of the integrated package. The modified aircraft would be subjected to flight evaluation and systems demonstrations over approximately a two-year period to validate concept feasibility and to develop an experience data base useful to industry.

The emphasis of this program would be directed towards reducing the complexity and number of avionics and control circuits and components, optimizing pilot workload to improve crew performance and decision making, reducing the need for maintenance and allocated costs, exploiting a multi-function hardware and software capability, and achieving fail-free display redundancy.

The overall program duration would be eight years. Phase I, systems integration feasibility and concept definition, would be two years in duration. Phase II, which would include system design, aircraft acquisition and modification, ground tests and simulation, would be six years long, and would conclude with a two-year flight test and evaluation of the selected system concept.

Large Composite Primary Aircraft Structures

The objective of this activity would be to provide full-scale verification of technology readiness for large composite structures (e.g., wing and fuselage) for subsonic transport aircraft. The Composite Primary Aircraft Structures (CPAS) element of the ACEE program has accelerated the application of composites to secondary and small primary structures in transport aircraft. Follow-on CPAS efforts planned under the ACEE program will carry the development of composites technology for large primary aircraft structures through the technology validation stage.. Large-size primary structures ground test articles (e.g., small fuselage sections or sub-assemblies and wing box beam assemblies) will be fabricated and tested.

Building on this foundation, a Large Composite Primary Aircraft Structures technology readiness program would provide a level of confidence that would enable industry to commit to production of large primary composite structures.

This program would consist of full-scale fabrication and ground testing of a wing and a major generic fuselage section. The resultant technology would provide a valid data base for full-scale tooling and fabrication methods, as well as structural integrity.

The approach would be to satisfy major technology needs. For the wing, the major technology needs are:

- -- durability, damage tolerance
- -- fuel containment, protection
- -- crashworthiness, fuselage and landing gear interface
- -- manufacturing
- -- quality assurance

For the fuselage, the major technology needs are:

- -- structural acoustic design
- -- pressurized cabin design
- -- post buckling
- -- passenger protection
- -- manufacturing

Major airframe industry involvement should provide enough data and methods validation for industry to confidently define and qualify point designs that will lead to production commitments involving large primary composite structures. More specifically, the following would be the technology or technology-related program goals:

- -- verified prediction capability
- -- verified design concepts for strength critical structures
- -- qualified manufacturing processes at acceptable costs
- -- solution of critical wing/fuselage/empennage technology issues
- -- company confidence for aircraft warranty
- -- FAA approved data base

Program duration, contingent upon completion of the presently planned CPAS tasks, would be four years.

3.2 SUPERSONIC TRANSPORT

The only operational SST in the world today, the Concorde, has demonstrated the technical feasibility of transatlantic supersonic commercial transportation and the potential for an expansion of air routes where speed is a vital factor in international commerce. However, the Concorde has major deficiencies which inhibit its development beyond the pathfinder role it is now playing. These deficiencies must be overcome for any future SST to be economically viable and environmentally acceptable. The operating economics of the Concorde are seriously constrained by the decisions made when it was designed and by the technologies available at the time, almost two decades ago. A successful SST of the future must have D.O.C.'s competitive with future subsonic transports, long range, minimal noise and good subsonic performance for operations over areas where sonic booms are precluded.

The advanced technologies essential to an economically viable and environmentally acceptable second-generation SST have been identified as a result of the NASA and industry research in the Supersonic Cruise Research and the Variable Cycle Engine Component programs. They encompass the major disciplines of aerodynamics, structures, propulsion and propulsion/airframe interactions and systems integration. All of these technologies must be matured and validated before a development option can become a reality.

3.2.1 Technology Needs

All work to date has been directed only to "technology identification." The current program is seriously deficient in funding level and technical depth <u>if</u> there is ever to be any intention to provide either a "technology validation" or a "technology readiness" posture in the U.S. aerospace industry. The consensus of opinion of industry and NASA, presented to the Congress in two separate NASA reports (References 8 and 9), is that an extensive amount of work is required to reach either level of technology. The current program does not provide for continuation of the Variable Cycle Engine Component (VCEC) program. The ongoing SCR effort does not provide the necessary depth in aerodynamic refinement and data base development, does not support large high temperature titanium and composite structures fabrication and life cycle testing, and does not support the larger scale hardware required to conduct meaningful propulsion system/airframe integration investigations. This latter area, in particular, requires an extensive continuing effort to provide an understanding of, and a data base for, the integration of either of the variable cycle engine concepts with axisymmetric variable area inlets and coannular nozzles into podded nacelles on various airframe configurations.

3.2.2 Ongoing Research

The Variable Cycle Engine Component (VCEC) program, funded through FY 1980, and the ongoing level of effort Supersonic Cruise Research (SCR) program, represent the total U.S.

effort directed at advancing SST technology. These efforts, initiated in FY 1976 and FY 1973 respectively, have identified the significant technical improvements for design and construction of advanced SST aircraft with environmental compliance, reasonable fuel consumption characteristics, and economic viability.

The work on VCEC has been divided into two separate efforts with Pratt & Whitney (P&W) working on a Variable Stream Control Engine concept and General Electric (GE) working on a Double Bypass Engine concept. Each manufacturer is attempting to establish that very different component technologies, peculiar to each engine cycle concept, are in fact viable.

The ongoing SCR program is divided into two basic parts: the first is a group of "system studies" where each contractor and a NASA in-house team, using preliminary design techniques, assess the broad array of applicable technology on baseline aircraft concepts. These baseline aircraft concepts cover a wide range of cruise design Mach numbers, weights, range, payload, etc., and provide a means for making trade-off and sensitivity comparisons. The second part is the discipline research and technology effort. These activities are focused on specific technology problem areas in aerodynamics, materials and structures, propulsion system/airframe integration, stability and control, and noise reduction. Efforts conducted in discipline research and technology have all been identified in the systems studies as "high payoff" or "critical" technologies.

3.2.3 Program

The objective of additional activities on supersonic transports would be to develop the primary technologies necessary to support a "technical readiness" effort. This could be accomplished by means of the three separate elements of this plan. These elements are: (1) Propulsion Technology, (2) Airframe Technology, and (3) Aircraft Systems Technology.

The schedule and funding for these activities are shown in Figure 5.

Propulsion Technology

The Propulsion Technology program would have 3 phases: Variable Flow Propulsion System Technology, Advanced Core System Technology, and Variable Cycle Experimental Engine(s).

The initial effort would be a broadened extension of the Variable Cycle Engine Component program. This would be initiated in year 1 through the Variable Flow Propulsion

System Technology program. A companion effort in Advanced Core Engine System Technology would be initiated in year 2 to provide in-depth systems technology for the sustained high temperature operational capability required for the core for the subsequent Variable Cycle Experimental Engine(s) (VCEE) effort.

The plan allows these two efforts to continue until year 4. Then the progress in these technologies would be brought together for the full demonstration of the variable cycle engine concept(s) in the Variable Cycle Experimental Engine(s) program. This effort, conducted on subscale engine sized hardware, would be the culmination of the VCE technology validation efforts. The VCEE program would bring together the unique cycle components, the advanced core technology, the axisymmetric inlets, the coannular nozzle, and the engine control system, and then would demonstrate the design process, performance, noise, fuel consumption, and life characteristics for a representative engine. The program would generate a data base for SST aircraft engine design. Additional data could be acquired through conduct of an engine flight test.

At this point, variable cycle engine design options should be available for a broad array of competitive civil SST aircraft applications or potential military applications in VTOL aircraft or mixed-mode strategic/tactical aircraft systems.

Airframe Technology

The Airframe Technology program would consist of two parts directed at problem areas peculiar to commercial supersonic transport aircraft: High Speed Aircraft Structures Technology, and Nacelle/Airframe Integration. These two efforts would be initiated simultaneously in year 2. The first addresses a major technology void in high temperature structures for high-speed aircraft. This five-year effort would be directed at material selection, design methodology, manufacturing process variables, fabrication and life testing of large-sized composite and titanium structures. The absence of any prior experience with either of these new materials for high temperature, flexible, primary aircraft structures requires that this rather large focused effort be performed to assure low development risk, establish confidence, generate a broad design data base, and provide some basis for cost prediction.

The companion effort in year 2 is the Nacelle/Airframe Integration program. This effort would develop a design methodology and an installation data base for podded nacelles on highly swept supersonic wings over the full speed range. The data base would be developed for both candidate axisymmetric variable area inlets (translating and expanding centerbody) and both variable cycle engine concepts with their preferred co-annular nozzle. These are the GE Double Bypass Engine with an annular plug nozzle and the P&W Variable Stream Control Engine with a co-annular ejector nozzle. The nacelle installation data base must also address advanced noise reduction technology, advanced engine controls, and operational conditions such as nozzle thrust reversal.

Aircraft Systems Technology

The Aircraft Systems Technology program would be directed at the broad systems problems inherent in all highly integrated supersonic cruise aircraft. The two elements are: The High-Speed Research Aircraft Definition Study, and the Supersonic Cruise Research-Technology Validation Program. The High-Speed Research Aircraft Definition Study would be initiated in year 2 with the intent to identify, define, and establish those technologies that require inflight investigation and validation. The effort would systemmatically develop the rationale and technical justification for the technologies that require demonstration in flight. The conduct of a definition study would then assess feasibility, identify alternate approaches and identify preferred paths with costs, schedules and milestones and the documentation necessary to support the decision-making process.

The second activity, which could be initiated in year 3, is the Supersonic Cruise Technology Validation program. The scope of this effort is predicated on the assumption that three specific efforts in this approach had been previously initiated. These are: Variable Flow Propulsion System Technology, Nacelle/Airframe Integration and the High-Speed Aircraft Structures Technology. Assuming these efforts are underway, this "Technology Validation Program" would expand the scope of all the discipline technologies to the levels outlined in the 1978 NASA Report to the Congress (Ref. 9). Completion of this effort as scheduled in this plan, with initiation in year 3, would provide "Technology Validation" during year 7. As noted earlier, the VCEE would be the only effort to continue beyond year 7.

3.3 LARGE CARGO/LOGISTIC AIRCRAFT

Air cargo movement in the civil market is growing at a more rapid rate than is passenger travel, and may achieve an appreciably greater penetration in the entire freight market. Military airlift is a major concern in world defense strategy and preparedness, and may in the future receive a high priority for improving logistic support capability. Accordingly, current views are that the development of a new large cargo aircraft may occur late in this century. Such an aircraft would benefit from new and advanced technology.

Much of the technology for a large cargo aircraft will flow from research programs structured around the needs of passenger transport aircraft, e.g., the ACEE program. In addition, system studies and exploratory research and technology tasks have identified some needs unique to large aircraft and some technology applications beneficial only to cargo aircraft. NASA recently funded an extensive air cargo study, Cargo/Logistic Airlift System Study (CLASS), which focused on the future demand for air cargo service and the characteristics for an integrated, efficient air cargo transport system. These studies appear to support the view that, if an advanced cargo aircraft design is carefully tailored to an integrated freight transportation system, the growth in air cargo volume may be substantially greater than would be extrapolated from past trends. However, the development of such a system by and for the private sector would depend upon its economic viability and the ability of advanced technology to contribute significant benefits in system economics and service.

3.3.1 Technology Needs

Technological improvements which would lead to better subsonic transports would, for the most part, also help to satisfy the needs of advanced large cargo aircraft. For example, development of composite structures technology for primary aircraft elements would lead to lower cargo aircraft weight and, consequently, better operating economics. There are, in addition, unique technology needs for lage cargo/logistic aircraft which include:

- o efficient configurations compatible with standard containers and rapid load handling.
- o Very quiet propulsion systems (probably turboprop) for curfew-free operations.
- o Larger aircraft sizes than currently operational--perhaps 2 to 3 times the payload capacity of the B747F--which implies:
  - Flying-wing, span-loaded or multi-body configurations,
  - Thick airfoils and wing structures suited to span-loading,
  - Active controls for stability and load alleviation,
  - Air cushion landing gear.
- o Configurations suitable for both civil air cargo and military logistics.

3.3.2 Ongoing Research

Extensive system studies have been conducted to identify large cargo/logistic aircraft system characteristics and their sensitivities to different aircraft technology levels. In addition, design concept studies have explored optional configurations, sizes and amounts of civil/military commonality. A span-loaded, flying-wing configuration has been tested in a NASA wind tunnel, and thick airfoil characteristics have been measured in a Lockheed-Georgia wind tunnel. In general, however, most of the current advanced technology research which could be applicable to large cargo/logistic aircraft is oriented toward passenger transports and is described in Section 3.1.

3.3.3 Program

The objective of an activity on Large Cargo/Logistic Aircraft would be to develop a technology base for the design of very large or specialized cargo aircraft systems, including consideration of unique ground systems requirements. The technology base of existing and ongoing aircraft programs would be extended into technological areas unique to cargo system design and operations.

Phase I would identify candidate concepts, establish the unique technology requirements, conduct wind tunnel and laboratory research on components and subscale systems, and define the larger-scale technology effort which would follow as Phase II. Major activity areas in Phase I would include advanced turboprop applications, propulsion/airframe integration, performance and flight operations/optimization, lightweight structural concepts, advanced wing design, boundary layer control applications, and unconventional aircraft configurations.

For the ground side of the system, Phase I would include consideration of terminal/intermodal interface systems, airfield compatibility (e.g., application of air cushion landing systems as they would impact the design selection process), and civil/military systems commonality.

The definition of follow-on, large-scale technology program requirements would be a final task under Phase I. Building on advanced integrated cargo system feasibility and market studies, Phase I would identify a generic class of freighter aircraft and applicable technology, and commence limited validation of these technologies. Technology validation on a larger scale and technology readiness efforts would be prescribed at a later date.

The schedule and funding for this program is shown in Figure 6.

3.4 CRYOGENIC-FUEL TRANSPORTS

Because the availability and price of petroleum-derived fuels will eventually become adversely affected by the depletion of the world's crude oil supply, long-lead research considerations for a potential transition to alternative fuels are required. Liquid hydrocarbon fuels derived from coal or oil shale can be refined to near current specifications, varying only as the processing cost is traded off against the cost of engine and fuel system modifications due to less desirable fuel properties. Although basic economic and technology impacts are relatively well understood for these alternate fuels, additional research is necessary and is currently underway and planned by NASA. Cryogenic fuels--liquid hydrogen (LH_2) and liquid methane (LCH_4)--are additional potential options with several attractive aspects. The practicality of these options is less well established at this time, and several critical technology needs have been identified.

3.4.1 Technology Needs

New insulation materials and fuel tank structures would be needed to permit the fuel tank to act as a structural member of the airframe. Improved materials and designs would also be required for the on-board fuel distribution and storage systems. Safety practices would need to be revised to reflect the unique new characteristics of cryogenic fuels. Aircraft may have double decks for the passengers, requiring new airport terminal design considerations. The characteristics of cryogenic fuels may be used to advantage in the propulsion system design to cool the engine and, in supersonic transports, in the wing design to cool the surfaces which are subject to high atmospheric heating.

Liquid methane has received less intensive study than liquid hydrogen to date, but appears to be potentially promising. Methane is readily derived from coal, contains slightly more energy per pound than Jet A fuel but less energy per cubic foot, and has a total fuel cycle more thermally efficient than one based on liquid hydrogen. The major advantages are lower cost and lower liquefaction energy requirements relative to liquid hydrogen.

The various factors mentioned above require comprehensive research programs to explore each option. Technological considerations which affect the planning and evaluation of these research activities include:

- physical characteristics of cryogenic fuels.

- costs of producing cryogenic fuels and of developing the equipment and systems to produce and distribute them.

- advantages and disadvantages of each fuel candidate in terms of aircraft performance, acquisition and maintenance costs, environmental acceptability, etc.

- suitability of cryogenic fuels from a user's point of view, e.g., what modifications or major changes are required in operations, equipment, procedures, etc.

- problems associated with ground handling and storage in terms of space, cost, safety, etc.

Concept studies of cryogenic-fuel aircraft systems have identified the need for detailed validation of the technologies required for tanks and insulation, delivery lines and valves, pumps and pump bearings, and flow monitoring instrumentation. Another area which deserves study is the conceptual design of aircraft and propulsion systems based upon the inherent qualities of cryogenic fuels for such purposes as cooling the engine or improving aerodynamic laminar flow, thus decreasing drag. Safety also requires substantial research. The absolute and incremental potential hazards from major fuel spills and aircraft accidents are still largely undefined. The systematic distribution, handling, and storage of cryogenic fuels at airports will also need to be addressed in more detail.

3.4.2 Ongoing Research

NASA's predecessor, the NACA, conducted liquid hydrogen aircraft engine research over 20 years ago, including flight tests. NASA studies of liquid hydrogen-fueled subsonic transports, and less detailed studies for supersonic transports, have identified the major potential advantages and technological problems, and ascertained the conceptual feasibility and comparative cost effectiveness of such transports relative to conventional designs.

Studies and exploratory research have also been carried out in the areas of on-board fuel storage and transfer components (insulation, pumps, and materials compatibility), boiloff recovery, hydrogen liquefaction (efficiency improvement), and hydrogen production from coal (cost and efficiency estimates for advanced technology processes). Liquid hydrogen spill hazard experiments are being planned, and complementary analysis methods are being developed. Data and practical experience from the space program have been incorporated into the cryogenic-fuel transport studies and research activities.

3.4.3 Program

Two activities have been identified as the elements of an expanded program on cryogenic-fuel transports: (1) Cryogenic-fuel Aircraft Technology, and (2) Terminal System Technology for Cryogenic-fuel Aircraft with the schedule and funding shown in Figure 7.

The objective of the Cryogenic-fuel Aircraft Technology effort would be to identify candidate concepts, provide a limited technology data base, and show proof-of-concept for a representative flight system. The program would be phased, with Phase I establishing the technology foundation for flight demonstrations and operational experience which could be included in Phase II. In Phase I unique technology requirements would be identified and investigated in the areas of structures, propulsion, instrumentation, flight operations and safety, and in fuel provisioning and handling. A limited amount of flight evaluation might be desirable. Requirements for a Phase II technology development effort would be defined.

The objective of the program for Terminal System Technology for Cryogenic-fuel Aircraft would be to refine candidate concepts, provide a limited technology base, and show proof-of-concept for a representative ground terminal system for servicing cryogenic-fuel civil transports. Very limited investigations have been made to date of the technology needs of airport ground systems for servicing transport-class cryogenic-fuel aircraft. Servicing in this context means accepting and storing the fuel at the airport, dispensing fuel to aircraft, defueling aircraft, recovering boiloff, transferring fuel between tankers and between ground storate vessels, and conducting housekeeping operations in response to leaks, spills, etc.

Taking into consideration the liquid hydrogen storage and handling experience from the space program, configuration concepts would be developed for an airport ground system for cryogenic fuels. A fuel system simulator and mock-up would be fabricated to investigate interfaces and compatibility of ground and flight systems suitable for passenger transport and cargo aircraft. Criteria would be defined for future follow-on experimental programs.

3.5 ROTORCRAFT

As a result of research and technology efforts in recent years, modern rotorcraft incorporate impressive improvements in performance, reliability, quietness, and vibration reduction over previous designs. For the first time, helicopters have been specifically designed for civil markets and for civil environments. In general, however, the rotorcraft field has lagged that of conventional fixed-wing aircraft by 20 to 30 years. One consequence of this is the possibility of some very exciting and beneficial technology advances which could be expected in the next two decades. The rotorcraft incorporating these advances could be "jet smooth," quiet, capable of all-weather operation, and as safe as any aircraft built for the civil transportation system.

Safety could be enhanced through the utilization of highly reliable structures, rotor systems, propulsion systems, and self-checking avionics. These advances could be coupled with the rotorcraft's unique capability for vertical landing in very small areas. Vibration reduction could be obtained through the use of improved rotor systems designed by advanced analytical techniques and incorporating advanced materials such as composites. Improved vibration isolators and absorbers, bearingless rotor systems, active control technology and higher harmonic control systems could also be used to reduce vibration and gust sensitivity to a level approaching that of the "smoothest flying" fixed-wing aircraft.

Improvements in the aerodynamics of rotor blades, tip shapes and aeroelastically conformable rotor designs, terminal area airspace utilization procedures, avionics and controls, and engine/transmission designs could result in quiet, highly reliable, all-weather rotorcraft with internal and external noise levels very acceptable to both passengers and community. Although direct operating costs could be reduced significantly from today's levels, they would remain above those of other modes of transportation. However, the total economics of rotorcraft transportation, including ground access time and indirect costs such as ground infra-structure and land costs, could be competitively advantageous over other modes for stage lengths up to 500 n.m. Such total system economic advantages are just starting to be recognized and could prove especially beneficial in regional and urban short-haul missions.

3.5.1 Technology Needs

The signs of the key technical ingredients that could make the future opportunities possible can be seen in today's research and development results. They would certainly be welcomed by the growing number of civil and military users of rotorcraft. Yet, the translation of future opportunities into reality will require many coordinated inputs--not the least of which is putting verified advanced technology in place so the rotorcraft manufacturers can design new vehicles with low technical risk.

Some prime examples of the important relationships between users, designers and technology needs are as follows:

<u>Noise</u>

- The user wants rotorcraft with low internal and external noise to assure passenger and community acceptance.
- The designer must have criteria and noise prediction methods for external broad-band and impulsive noise generated by the rotors and propulsion system and for internal noise generated by transmissions, and engines.

- o The state-of-the-art is totally inadequate for predicting noise for completely new designs. The current capability is based on data trending and evolutionary design changes.

Performance

- o The user is seeking increased productivity from new rotorcraft. With increased efficiency, size, and speed, the user expects a more profitable operating capability.

- o The designer must integrate a total system of propulsive, structural, aerodynamic and contol components to achieve higher performance. This requires a data base and verified analytical methodology in advanced light-weight structures, durable and efficient propulsion components, and rotor design tools addressing airfoil, tip shape, rotor/airframe flow field, and aeroelastic analyses.

- o The state-of-the-art is inadequate. Exploratory results show great promise, especially in rotor performance improvements, drag reduction, durable composite structures, and transmission systems. However, a sound data base and verified design methodologies are not available to allow the development of low risk new designs.

Vibration

- o The user wants a "jet smooth" aircraft not only to meet the needs of passenger comfort but to avoid the mechanical and avionic system failures attributable to excessive vibration levels.

- o The designer must have the capability to predict and modify analytically the dynamic response of the airframe and the oscillatory forces imposed upon the vehicle.

- o The state-of-the-art is also inadequate. Only recently have prediction methods begun to show promise. All too often, a design must be iterated by cut and try hardware changes that are time consuming, costly, and involve substantial technical risk.

Other areas of high payoff such as fly-by-wire control, advanced displays, integrated propulsion/airframe control, advanced composite materials and new rotor concepts also have not reached a point of readiness for full application to advanced rotorcraft.

3.5.2 Ongoing Research

The Nation's research and development in rotorcraft is conducted by various segments of the helicopter industry, universities, the Department of Defense, and NASA. The Federal Aviation Administration is also moving ahead with increased emphasis on R&D addressing their role in rotorcraft airworthiness and operating procedures certification. While the emphasis in the FAA, and increasingly in the DOD, is placed on more "near term" research and development keyed to user requirements, NASA emphasizes more broadly based research of a more "long term" nature. An important adjunct to the NASA program is the joint research arrangement with the U.S. Army. Through laboratories collocated at NASA's Ames, Langley and Lewis Research Centers, the Army's Aviation Research and Development Command conducts research in aeromechanics, structures and propulsion. A significant portion of the Army research staff work directly with NASA groups on research of common interest.

The major portion of the ongoing NASA research is directed toward rotorcraft aerodynamics, dynamics and aeroelasticity. Tests of small- and large-scale rotors and vehicle configurations in wind tunnels and associated flight tests of full-scale systems are conducted to explore, document, and understand the complex flow fields and resulting dynamic loads and performance. Another segment of this research deals with rotorcraft flight dynamics, concerned with the stability, control and flying qualities characteristics. In all these areas, ground and flight testing are augmented by analytical studies.

A modest level of effort is also directed at studies to define technology needs, advanced vehicle concepts, mission criteria, and market assessments in order to assist in planning future rotorcraft technology directions and priorities.

Two program elements, Advanced Rotor Systems and Advanced Transmission Systems, represent commitments to specific research milestones. The Rotor Systems research involves the necessary ground and flight testing to bring promising concepts to a state of readiness for application in advanced rotorcraft designs. The Transmission Systems research emphasizes the integration of available new technology in bearings, gears, seals, and lubricants to the special needs of rotorcraft for lightweight, quiet and reliable transmission systems.

In 1972, NASA and the Army agreed to jointly fund and manage the Rotor Systems Research Aircraft (RSRA) and the Tilt Rotor Research Aircraft (TRRA or XV-15), each program involving two aircraft. The RSRA will be used for rotor systems research and for general flight research to develop and verify advanced analytical methods related to pure and compound helicopter configurations. The TRRA will be used for proof-of-concept flight testing and then for civil and military mission suitability investigations.

3.5.3 Program

While the ongoing research is addressing some of the priority issues in rotorcraft technology, it does not represent an adequate response to the technology needs. In early 1978, a special Rotorcraft Task Force, consisting of representatives from NASA, DOD, and FAA, was created to determine the technological needs and opportunities related to future civil and military rotorcraft, and to prepare a program plan for responsive NASA research. The Task Force solicited inputs from airframe and engine manufacturers, operators, and other Government agencies. Its deliberations resulted in the definition of four major advanced rotorcraft technology elements: aerodynamics and structures, flight control and avionic systems, propulsion, and vehicle configurations. In general, the proposed program would place primary emphasis on design methodology where the development and verification of analytical methods are built upon a sound data base.

The schedule and funding for the accomplishment of additional rotorcraft research activities, modified and rephased for different buildup rates from that in the Task Force plan (Ref. 14), are shown in Figure 8.

<u>Aerodynamics and Structures</u>

In this element, phased programs would improve and develop design methodology in key areas of aerodynamics, structural dynamics, acoustics and advanced materials applications.

Aero/Acoustics: The first program phase, years 1 through 4, would provide for systematic small- and large-scale tests of a rotor family and a complete helicopter configuration with heavy emphasis on detailed flow, acoustic and aerodynamic parameter measurements and the development of improved analytical prediction methods. The next phase, years 3 through 6, would involve the use of design methodology to design and predict the performance and noise characteristics of specific second-generation rotors. This would then be followed, in years 6 through 11, by testing to check out the predictions and to update the methods, as might be required.

Vibration Reduction: The first phase, years 1 through 4, would concentrate on airframe loads and structural modeling methodology. An industry/Government team approach would be utilized to assist in generating more widely acceptable and usable prediction and modeling methods. Program elements related to the vibration prediction methodology would include in-service flight load measurements during civil helicopter operations, the use of active controls to suppress vibration, and internal noise reduction. Later phases of the program, years 3 through 7 and 6 through 11, would address the use of advanced materials and advanced structural and aeroelastic concepts in hub/blade design methodology.

Composite Airframe: The first phase of this program element would start in year 2 and would include composite fuselage design studies and associated experimental assessments of critical design features, particularly related to high curvature and highly loaded elements. The second phase, starting in year 6, would consist of build-up and thorough ground-based testing of a major fuselage component such as a center section or upper fuselage assembly. This program element would be coordinated with the Army's near term, first-generation composite airframe technology program.

Flight Control and Avionic Systems

There are increasing demands and opportunities for rotorcraft flight control and avionic systems to provide improved performance, efficiency, reliability, and handling qualities; pilot workload improvements; vibration reduction; and noise reduction. To help realize this potential, the program would have two research elements which focus on fully integrated systems designs that properly interrelate rotor, propulsion, airframe/structure, and flight control avionic systems.

All-Weather Rotorcraft: In years 1 through 3, systems concepts would be defined, constructed and evaluated through simulations. Exploratory flight research under highly instrumented conditons and operational flight assessments would be conducted in a second phase, starting in year 2. This would be followed by flight testing of fully integrated systems in years 5 through 9. There are two main all-weather rotorcraft systems technology thrusts. These are remote site "on-board" systems technology and high density 3D/4D guidance, including air traffic control interfacing and integrated Category III systems technology.

Active Control Technology: Two main task areas would be addressed, full-authority vehicle systems and mission capability improvement. During program years 3 through 6, full authority systems technology would emphasize the design, evaluation and validation of flight critical, full authority concepts typically associated with fly-by-wire, fly-by-light and control configured vehicle technology. In a second phase, years 7 through 10, mission capability improvements would be addressed. Primary emphasis would be placed on the design and validation of "local area" high precision, low altitude, fast response guidance and navigation system technology.

Propulsion

Three program elements have been defined which are responsive to the needs of rotorcraft manufacturers and users, both civil and military. The major emphasis would be on improved durability and maintenance characteristics of rotorcraft propulsion systems, including small engines.

Engine Component Design Methodology: This program element would involve three phases starting in year 1. During the initial phase, analytical design techniques would be established using both computational and experimental methods. In the second phase, starting in year 4, parametric experiments would be conducted to develop a strong empirical data base for single stage axial and centrifugal compressor stages. Effects of unsteady flow and turbulence on vane and blade heat transfer would also be investigated. A study would be conducted to establish the critical design criteria for small turbine engine combustors. In addition, full-authority digital electronic control components would be evaluated in terms of high reliability and low cost. In the area of diagnostics, maintenance records of rotorcraft users and engine manufacturers would be examined to identify the most prevalent causes of failure or reasons for removal of rotorcraft propulsion system components. In the last phase, years 7 through 10, preliminary bench testing to verify the new design methods would be conducted.

Power Transfer Technology: In the first phase, starting in year 2, emphasis would be on obtaining a fundamental understanding of noise and vibration, and the development of analytical prediction techniques and design concepts for noise and vibration reduction. Diagnostics would be addressed in a manner similar to the engine diagnostic effort mentioned previously. Manufacturer and user records would be evaluated, and selected components would be "tracked" during in-service operation. Sensors and displays would also be developed and evaluated in system condition monitoring studies. In a second phase, starting in year 6, major task emphasis would be on identifying, developing, and proof-of-concept demonstrating advanced power transfer components and systems.

Systems Integration: Systems condition monitoring would be addressed through the application of advanced technology sensors for detecting such internal factors as gas, metal, and lubricating oil temperatures in critical locations throughout in-service propulsion systems. This data, from a variety of vehicle and mission types, would be used to develop analytical models for predicting the life history of critical components. Various methods of augmenting engine power would be analytically evaluated. Innovative techniques would be sought and experimentally explored to define technological capabilities. A complete engine/electronic control/transmission system would be assembled and experimentally evaluated in a ground test facility starting in program year 4. Improved engine inlet and separator aerodynamics and ice protection would also be evaluated in scale-model tests.

Vehicle Configurations

A research plan has been defined which would be aimed at establishing a technology base in high-speed and large rotorcraft concepts. The overall approach would be to start with evaluations using existing vehicles and the conduct of ground-based testing and studies of advanced systems and concepts.

High-Speed Concepts: Starting in program year 1, ongoing proof-of-concept flight tests of the XV-15 Tilt Rotor Research Aircraft would be extended to acquire a thorough documentation of tilt rotor aerodynamics, flying qualities, stability and control and structural loads characteristics. A similar program would be carried out on the Advancing Blade Concept (ABC) vehicle as a follow-on to the current Army/Navy/NASA program. Additional preliminary design studies, scale-model tests, and simulation studies of other promising high-speed concepts would also be conducted. In program years 4 through 8, advanced systems would be fabricated and flight tested.

Large Rotorcraft Concepts: A broad range of large rotorcraft concepts and configurations would be evaluated in the initial phase starting in year 1 by concept studies, ground-based testing and flight testing of available hardware. The initial effort would involve the assessment of various options for heavy lift, cargo and transport missions. A key consideration of the heavy-lift studies would be the feasibility of providing a high-speed ferry capability for heavy-lift vehicles. The large rotorcraft program would include the early ground-based testing of the XCH-62A transmission system to provide a technical data base on large drive systems for future civil and military heavy lift, cargo and transport vehicles. This transmission technology would also have application to new V/STOL designs. In year 5, the emphasis would shift to ground-testing of other systems such as rotors, control systems, and advanced load handling systems.

3.6 COMMUTER TRANSPORTS

The commuter airlines have experienced significant growth over the last decade and, for the most part, have had annual growth rates larger than those of the domestic trunk and local service airlines. The commuter airlines in the U.S. are currently operating a wide variety of small domestic and foreign built aircraft, most of which were originally designed for the general aviation market, and which are operationally and economically severely compromised for commuter airline operations.

3.6.1 Technology Needs

There appear to be significant technology opportunities that can improve the passenger/community acceptance and operational economics of future small transport aircraft. Commuter aircraft operate, on the average, over stage lengths of about 100 miles, and this imposes unique design considerations and, consequently, technology opportunities. On-time dependability is of paramount importance because a 30-minute delay is much more detrimental to a 30-minute short-haul flight than to a 5-hour long-haul flight. Although speed is certainly important to the passenger, it is perhaps more important to the operator because of its direct effect on aircraft productivity and, hence, on operating cost.

Many passengers remain somewhat nervous about flying, especially in many of the "non-airline" looking commuter aircraft, and appreciate as smooth a ride as possible. Unfortunately, because most current commuter aircraft have low wing loadings and spend a large portion of their flight time in the more turbulent lower altitudes, their ride quality is not as smooth as that of the larger jet transport aircraft.

Commuter aircraft operational economics can be improved by better aircraft performance capabilities which allow them to be operated from short runways with full payload, to avoid delays by integrating smoothly into the air traffic control system shared with larger aircraft, to cruise at higher speeds to minimize block time, and to have improved climb performance to allow increased aircraft payload to gross weight.

There are uncertainties in regard to the application of advanced technology in the development of U.S.-manufactured future commuter transports. Commuter airlines perceive a gap in the current U.S. manufacturers' capability for building new aircraft in the 30- to 60-passenger capacity range. These aircraft may be too small for the large jet transport builders (Boeing, Douglas and Lockheed) and too large for the major general aviation manufacturers (Beech, Cessna and Piper). There are also uncertainties with regard to the certification requirements and costs of some new technologies. In addition, development costs of new aircraft are significant and risks associated with unproven advanced technology tend toward conservatism--thus requiring extensive demonstration of technology readiness.

3.6.2 Ongoing Research

NASA's present program is primarily aimed at the identification of the most promising small transport aircraft technology elements. Technology application study contracts recently have been awarded to several airframe, engine and propeller manufacturers. In these studies, the design and operational characteristics that constitute the main constraints to improved cruise and terminal area performance will be identified and examined, and the potential for improvement, by the cost-effective application of advanced technology, will be evaluated. The studies will define the research required to elevate the appropriate advanced technology to the point that it could be applied to new aircraft with confidence.

3.6.3 Program

In view of the uncertainties which exist at the present time, a two-phased activity is in order with regard to commuter transport technology. Phase I would have as its objective the performance of studies and preliminary analytical and ground-based experimental research in the technologies found to be most critical and beneficial to the development of improved commuter aircraft. The selected technologies would be established from prior projected benefits analyses in which the potential timing for the introduction of advanced technology aircraft into the fleet would be estimated and the resulting benefits over time quantified.

Phase II objectives would include the development of a design data base and certification criteria, the validation of advanced concepts, and the demonstration of technology readiness in the major important technical disciplines. Aerodynamics research could include wind-tunnel tests and selected flight tests where appropriate. Ground-test experiments could be performed to establish engine/airframe integration effects. Propulsion system research could include the design and test of critical advanced components. Advanced structures could be fabricated and advanced systems, such as flight controls and icing protection, could be simulated and tested.

The schedule and funding for this program is shown in Figure 9.

3.7 GENERAL AVIATION

Advanced technology can be used to meet a number of emerging problems and challenges affecting the future of General Aviation and its manufacturing industry, including the possibility of growing fuel shortages and escalating costs; the interrelated issues of increasing congestion around airports and in the airways; safety and environmental impact; and the threat of growing, competent and aggressive foreign competition determined to capture a larger share of the world market. In addition, significant opportunities exist for broadly increasing the utilization of G.A. aircraft, an important example being the large potential in aerial applications of materials for agriculture and related purposes.

3.7.1 Technology Needs

Key technology needs of General Aviation are related to fuel efficiency, enroute and terminal operational effectiveness, and congestion.

Both the economics and future usefulness of G.A. will be adversely impacted by growing problems of aviation gasoline supply and increasing fuel costs. Improved fuel efficiency can result from at least four types of improvements: better engines and propellers; reduced aircraft drag; reduced aircraft weight; and more efficient fuel management, through onboard system improvement and improved navigation techniques and air traffic control methods. Conceivably, up to 50 percent reductions in fuel use for certain types of G.A. aircraft could be realized if all types of improvements were achieved.

Very few fuel-efficiency improvements have appeared in forty years in the gasoline fueled, spark ignition reciprocating engines which power the vast majority of G.A. aircraft. With the increased incentives for savings, it can now be seen that there are a number of possibilities for increasing the thermodynamic efficiency of these engines. Variable timing, better combustion chamber design, more effective cooling designs, and better fuel preparation and control processes have all been investigated in exploratory NASA research and technology programs for G.A. engines. This work clearly indicates that it should be possible to develop some or all of these potential improvements which could be compatible with general aviation requirements for safety, reliability and operating range. In addition to basic engine modifications and design changes, improved turbosuperchargers for G.A. engines could also permit more efficient higher altitude operations, with resultant additional fuel savings.

Other recent NASA investigations of engine technology for general aviation have extended into less conventional types. Basic improvements to rotary combustion (Wankel-type) engines to reduce their fuel consumption to acceptable levels seem feasible; if perfected, the rotary engine would offer for G.A. the inherent potential advantages of lower weight, reduced mechanical complexity and less vibration. Similarly, recent studies of high-speed, lightweight, supercharged two-stroke cycle diesel engines indicate considerable merit for this unconventional power plant approach for general aviation. Both the advanced rotary and diesel engines could be developed for multi-fuel operation, reducing future aviation gasoline demand.

The advantages of gas turbine engines in aviation are well known, particularly their high reliability and long life, low vibration, mechanical simplicity and low specific weight. In the past, these benefits have been denied to all but the largest, most powerful and highest performance G.A. aircraft, which are also the most costly. Excessively high costs of hardware and high fuel consumption have both been barriers to successful development and acceptance of smaller gas turbine engines for the lower performance classes of G.A. aircraft. Recent studies have indicated that significant improvements in both cost and fuel consumption may be achievable in the future, bringing the long hoped-for reality of affordable turboprop engines to a much larger portion of the general aviation spectrum of aircraft. Key to this achievement is improved engine component performance coupled with designs amenable to low cost manufacturing methods which do not sacrifice performance.

Perhaps 99 percent of G.A. aircraft are propeller driven, and will continue to be so in the future for all but the more high-performance (high-speed) types. As with engines in G.A., few improvements in propeller aerodynamic efficiency have appeared since World War II. However, improved airfoils and aerodynamic computational methods, together with the use of appropriate composite structural design methodology, could make possible major improvements in G.A. propellers in the future. As much as 10 percent fuel savings might be realized for certain types of aircraft, as well as reduced propeller blade weight and increased structural integrity.

Most of the actual power (and energy) needed by an aircraft is used to overcome drag, and many opportunities for basic drag reduction exist in G.A. One of these could be the use of airfoil concepts based on maintaining a region of natural laminar flow, which has recently been explored at small scale for specific G.A. flight regimes. Another area of opportunity is the reduction of cooling drag in many G.A. aircraft engine installations, while still other opportunities exist for systematizing the reduction of propeller/ nacelle/wing/ body/tail interference drag components through advanced design and analysis approaches. Aerodynamically smoother surfaces resulting from optimal applications of composite structures could also result in significant skin friction and form drag reductions. And, finally, reexamination of unconventional aircraft aerodynamic arrangements (such as canards) may reveal practical and effective means of reducing trim drag.

The energy saving potential of weight reduction in G.A. rivals the benefits of propulsion or aerodynamic drag improvements. A clear opportunity is found in the effective use of composite primary structures chosen for optimal use in G.A. applications. Other weight reductions are, of course, introduced by all improvements in propulsion efficiency and drag reduction which result in reducing the required fuel load for a given mission.

In avionics, the most important opportunity lies in the area of improved and affordable avionic systems for G.A. Simplified and integrated avionics systems would perform many navigation and flight management tasks to lighten pilot workloads, leading to more attentive, efficient and safe operation of the airplane. Better systems could be made available over the entire spectrum of G.A. aircraft, not merely the higher performance types. The improved avionics could also permit more efficient navigation, weather avoidance, flight control, engine control and fuel management, with resultant time and fuel savings.

Much can be done to improve structural designs to provide greater protection for G.A. aircraft occupants in the event of crash accidents. Energy absorbing load limiting structural concepts would provide such capabilities. Safety can also be enhanced in the stall/spin area, a prime cause of G.A. accidents. Not only is this a safety concern, it is also an operational limitation in the terminal area. Significant improvements in understanding the phenomena and in providing design remedies are needed.

In addition to these technology needs to forestall or ameliorate emerging threats to the future of general aviation, significant new opportunities will continue to arise for the use of aircraft in business and industry. An example of considerable importance is the extended use of aircraft in agriculture for the efficient, safe and economical application of fertilizers, insecticides and seeds. The technology requirements in this area are for improved means of accurate control of both liquid and solid materials, at more highly productive rates. Based on NASA research and studies of the last few years, integrated system design concepts rather than add-on material distribution devices represent the most fruitful opportunities for major advance. In these, the airplane aerodynamic flow fields as well as its on-board sensing, flight management and control systems, would be utlized as an integrated whole.

3.7.2 Ongoing Research

The bulk of ongoing R&T directly related to G.A. problems and opportunities is undertaken by NASA, part of it in-house, part of it through university grant or contract, and part of it (roughly half) performed under contract by industry. NASA's essential role in research and technology for General Aviation is to explore fundamentals and demonstrate technology which can be useful to the industry, with primary emphasis on issues for which generalized technology solutions are needed. The NASA program in general aviation encompasses all the major technical disciplines: aerodynamics, flight dynamics, stability and control, materials and structures, propulsion, avionics and human factors, and includes basic systems design and interdisciplinary concerns, including operations and safety.

In addition to R&T Base efforts in each of the technical disciplines, two Systems Technology programs in general aviation are presently being conducted. One of these, to be completed within FY 1979, is the Quiet, Clean General Aviation Turbine program (QCGAT), which is being conducted to demonstrate the applicability of large engine noise and emission reduction technology to smaller turbofan engines for use in G.A. executive aircraft. The other Systems Technology program is the Demonstration of Advanced Avionics System (DAAS). It includes an industry contract program to provide the critical information and architecture required for the design of a reliable, low-cost, advanced avionics system suitable for G.A. aircraft to enhance safety and utility, and to serve as a basis for subsequest industry design development within the coming decade. It will be completed in FY 1982.

Despite the breadth of the current program directed toward General Aviation, the depth and pace of the effort will not at present provide the full range of validated technology which will be needed for industry's proper address of the problems and challenges outlined previously.

3.7.3 Program

Several important opportunities have become visible as possible major focused technology activities to provide basic information and technology demonstrations in selected General Aviation areas. The successful, timely conduct of these efforts would be the key to industry's preparation to address, both adequately and with confidence, the several problems and challenges it must face in the next decade and beyond.

Schedules and funding for these activities are shown in Figure 10.

Propulsion Technology

Three major objectives would be included in the area of propulsion: Advanced Propellers, Advanced Internal Combustion Engines, and a General Aviation Turbine Engine program.

Advanced Propellers: Systems studies and precursor research on propellers for low-to-moderate speed applications for G.A. have led to the definition of a focused technology opportunity for General Aviation Propeller (GAP) technology. The objectives of this program would include aerodynamic efficiency improvement, noise reduction, weight reduction and improved structural characteristics and fatigue life. Modern analytical computational techniques for propeller aerodynamics, acoustics, and composite structural design tailoring of mechanical properties would be applied to the optimization of propeller characteristics for several distinct application regimes in general aviation. Envisioned as a five-year program, the first phase would require first a systematic evaluation of design parameters, followed by small-scale model testing and analysis, and ultimately the evolution of full-scale advanced propeller designs for ground- and wind-tunnel testing.

Advanced Internal Combustion Engines: This 5- to 6-year technology program enhancement would have three major phases. The first, lasting about 3 years, would be an evaluation of representative modifications which might be made in present types of gasoline-fueled internal combustion engines to improve fuel economy, life and operational envelopes. These modifications would include improved cooling design and reduced cooling drag installation concepts, electronic controls and condition monitoring, and advanced turbosupercharging technology. This work would subsequently enable the industry to define and develop relatively near-term improvements which would not mandate major manufacturing and tooling changes.

The second phase, begun concurrently with the first and lasting about three years, would explore the critical component design technologies for more advanced spark ignition reciprocating engines, rotary combustion engines, and two-stroke cycle diesel engines for G.A. applications. Based on the comparative results of this work, a decision would be made to select the most promising of the three advanced engine concepts for an experimental engine technology demonstration. The engine demonstration phase would require 2 years, and would explore the essential characteristics of an advanced engine concept, thereby substantially reducing the technical risks of subsequent industry development.

G.A. Turbine Engine: This technology program, extending over a five-year period, would develop and demonstrate the necessary technology to establish the feasibility of fuel efficient and affordable turboprop engines for general aviation. Power levels of greatest present interest correspond to those of the larger turbosupercharged aircooled reciprocating engines for G.A., i.e. 300 to 400 horsepower at cruising altitude. The first of three sequential phases would include small engine component performance improvement and low-cost mechanical design and fabrication technology. The second phase would emphasize engine gas generator system technology, and the third phase would be devoted to experimental engine fabrication, testing and evaluation.

Aerodynamics and Structures Technology

Three major activities are included in this area: Natural Laminar Flow Wing technology demonstration, Aerial Applications System Technology, and Composite Structures Technology.

Natural Laminar Flow Wing Technology: Precursor R&T studies and wind-tunnel tests of new airfoils for G.A. drag reduction have shown the concept of maintaining a region of natural laminar flow (NLF) without boundary layer removal to be quite attractive for low-to-moderate airspeed applications. The Full-scale technology demonstration and evaluation of a NLF wing on an experimental aircraft would serve to verify the design concept and examine system design sensitivities such as wing/fuselage interference effects, the influence of the propeller slipstream, and actual surface smoothness requirements. The five-year, two-phase program would begin with characterization of the unmodified baseline aircraft to be used, and the design of the NLF wing including subscale wind-tunnel test configuration development and verification. In the second phase, the full-scale wing would be fabricated, integrated with the baseline airframe, flight tested and evaluated against predictions. Results of this program would provide major evidence of the feasibility of NLF wing concepts needed before any industrial development would ever be undertaken.

Aerial Applications Systems Technology: Systems analysis, wake modification techniques and materials dispersal technology research have led to the definition of this five-year technology program. Its objective would be to demonstrate the integration of aircraft aerodynamic design for dispersal system requirements to improve swath accuracy, uniformity and controllability, and to increase aerial applications productivity and safety. This technology demonstration would provide an important stimulus for subsequent system development within the industry.

Composite Structures Technology: This five-year technology program would add importantly to the development of the vital data base and design methodology needed before the potential benefits of composite primary structures for G.A. aircraft can be realized. Reflecting differing detailed design requirements, it is not likely that the identical material and structural characteristics being investigated for use in highly loaded, high-performance aircraft will be equally suitable in lower performance, lower cost G.A. aircraft. This program would assist in the establishment of necessary design approach differences, and would also emphasize crash load absorption requirements in composite structures.

Avionics, Control and Display Technology

This technology program would extend and broaden the objectives of the present Demonstration Advanced Avionics System program for G.A. It would emphasize four major areas: the development of concepts for single pilot workload reduction and air traffic control compatibility, particularly under IFR conditions; study the human factors and functional analysis aspects unique to G.A. in the foregoing situations; develop integrated systems design concepts; and conduct simulation, ground tests and flight evaluations of the new avionics systems concepts. It is expected that this program would extend over an eight-year time span, providing essential design concept evaluation and verification for use in G.A. systems of the 1990's.

3.8 FUNDAMENTAL TECHNOLOGY - PROPULSION

Fundamental propulsion technology advances pace major new engine systems by providing the basis for improvements associated with all principal aeronautics objectives covering performance, efficiency, economy, costs, productivity, safety, reliability, and environmental compatibility. When fundamental technology is integrated and focused on a particular engine system for further development and validation, as it is in many of NASA's propulsion programs, it becomes closely tied to a vehicle class having well defined mission and propulsion requirements. Major vehicle related advanced propulsion system technology programs are described under the individual vehicle headings, such as, the variable cycle engine technology program for advanced supersonic cruise aircraft, small engine technology for the short-haul utility class of aircraft, and the three major propulsion elements of the Aircraft Energy Efficiency (ACEE) program for CTOL aircraft. The advanced turboprop program, one of these ACEE elements, is also directly applicable to short-haul commuter aircraft.

In addition to these focused engine programs, there is periodically an opportunity to strengthen and enhance the fundamental technology base by initiating from within the ongoing program, new technology thrusts in areas which are generic and apply to many engine systems across a number of vehicle categories. Such an opportunity currently exists in several key technology areas--alternate fuels, engine durability, electronic controls, and engine/airframe integration. Propulsion systems for all vehicle types will benefit from additional advances which could be made in these areas. The following are descriptions of potential programs and their relationships to ongoing program elements for these key technology areas.

3.8.1 Alternate Fuels

With the escalating cost of jet fuels and the potential for serious shortages caused by supply dislocations, technology must be developed to allow aircraft engines to operate efficiently, safely, and with minimum environmental impact using fuels refined to broadened specification limits to increase fuel availability. These fuels will be refined not only from petroleum crude oil, but from coal and shale derived crudes as well.

Broad-specification fuels technology is particularly important to large commercial transport aircraft. But the large and growing fleet of turbine-powered helicopters and business and commuter aircraft will also be affected by fuel having relaxed specifications. In fact, because of size effects and mission profiles peculiar to helicopters and short-haul commuter aircraft, problems with small engines will, in many ways, be more challenging.

The objective of this aircraft alternate fuels effort would be (1) to investigate and define those component and system technologies peculiar to both large and small gas turbine engines and aircraft fuel systems when operating on broadened specification fuels, and (2) to evaluate broad-specification fuel thermal stability, freezing point, and combustion properties (and the technologies to accommodate changes in these properties in future fuels). Configuration oriented component and system technology studies would be conducted to determine constraints on fuel properties dictated by existing engine and airframe design limitations.

The ongoing NASA fuels program, underway since 1974, has been structured around characterization of shale and coal derived liquids as well as petroleum, and includes examination of the effects of a relaxation of existing aircraft turbine fuels specifications. As the program has progressed, it has become apparent that both a broadening of scope and an acceleration of pace would be consistent with the onset of serious supply dislocations combined with the unacceptable cost escalation of existing jet fuels. In such an expanded program, fundamental studies would be performed to assess thermal stability, freeze point, and liquid fuel combustion characteristics of candidate broad specification petroleum and synthetic fuels for aircraft. In-depth studies into coking characteristics, carbon formation and gumming characteristics, wax formation susceptibility, vaporization characteristics and other fundamental phenomena would be performed.

This program could be conducted over a ten-year period through in-house efforts at the NASA centers, contracts to industry and non-profit research organizations and grants to universities.

Results from the program would provide an extensive data base on fuel properties to permit adjustment of fuel specifications over a wide range to affect availability, cost, and sources of aviation fuel in the future, and to provide a technology base for the design of both large and small turbine engine combustion and fuel systems which would be compatible with these future fuels. Funding requirements for the program expansion are given on Figure 11, the near term phase being directed to fuel characterization and the more far term phase toward component and systems aspects.

3.8.2 Engine Durability

Since the introduction of the gas turbine in the early 1940's, engine pressures and temperatures have continued to rise as requirements for greater cycle efficiencies and improved performance have been imposed. Today, engine components are often subjected to gas temperatures as high as 2500°F. Of all the gas turbine components, those in the hot section--the combustor and the turbines--are most susceptible to deterioration and damage. These parts require the most frequent replacement, accounting for only 20 percent of the engine's weight but 60 percent of the engine's maintenance costs. In 1978, the maintenance costs for the hot section of high-bypass engines in the free world was 400 million dollars. By 1988, if unchecked, the cost would climb to as much as two billion dollars and is expected to continue escalating at this rapid rate unless the technology required for designing for durability is greatly improved.

The objective of a program in this area would be to develop analytical models and predictive tools that would allow improvements in durability to be designed into hot section components of advanced gas turbine engines and to verify these durability improvements in testbed engines.

Current efforts for improving engine durability are aimed mainly at developing coatings to minimize oxidation and corrosion of combustors, and turbine vanes and blades. Ongoing NASA efforts have been aimed at improving the strength and fatigue life of turbine vanes and blades by compositional changes in high temperature engine materials and by reducing material temperatures through the use of more efficient thermal barrier coatings. It appears, however, that significant improvements will only be possible through a better understanding of the complex environment and loading conditions that are imposed on the components of the turbine engine hot section.

In Phase I of this additional effort, the total environment within the hot section would first be defined. This would entail measuring the temperatures, pressures, and gas flow conditions around combustors, vanes, and blades. Thermal and mechanical loadings would then be measured with improved instrumentation which would require advancements in thermocouples and strain gages. The acquisition of these data would permit the designer to develop methods to accurately predict certain major inputs. These include local gas temperatures, heat transfer to the component, local and average component temperatures, local and average stresses and strains, the surface environment to account for chemical attack and erosion, appropriate thermal and mechanical properties of the materials, and the response of the material to various failure mechanisms induced by the environment.

Material stress-strain behavior would then be studied and put into forms compatible with finite element structural analyses computer programs. A nonlinear structural analysis methodology would be developed for use as a component design tool. Geometry modeling is also needed which would require the development of models for combustors, blades, vanes and turbine disks. The failure modes for all of these components would be defined and a criteria that defines failure would be established. Finally, all of these activities would be integrated into a life prediction methodology that would predict the mode of failure, where in the component this failure would occur, and when failure would occur.

In Phase 2, the analyses and predictive methods developed in Phase 1 would be verified at the component level. Actual engine components would be instrumented and tested in order to provide this verification. The life predictive models could then be improved where necessary. Funding requirements for the two phases of a program expansion are given in Figure 11.

3.8.3 Electronic Controls

Modern commercial gas turbine engines are controlled by conventional hydromechanical systems which are capable of adjusting only a limited number of control variables. Beyond these present day control systems, advanced full-authority electronic digital controls offer a tremendous opportunity for improving engine performance, reliability, and maintainability through improved power management and on-line engine condition monitoring. Digital controls for future engines can provide the flexibility which permits incorporation of a number of sophisticated control functions and variable geometry provisions to promote efficient engine operation and minimize hardware deterioration and its deleterious affect on engine performance and fuel consumption. Technology for achieving reliable instrumentation, sensors, software logic, control functions, and variable geometry actuators must be developed.

The objective would be to develop technology for highly reliable, full authority digital control systems, sensors, and actuators for advanced gas turbine power management and engine condition monitoring.

Digital controls which incorporate a number of sophisticated control functions and variable geometry provisions would be developed to provide efficient engine operation as well as an engine diagnostics capability for monitoring performance deterioration of the engine. Critical instrumentation and sensor technology and interface and fault-tolerant, self-correcting logic requirements would be developed and demonstrated. Advanced control features which would be investigated include self-trimming and accurate power rating control to reduce maintenance and improve hot section life by insuring that the engine operates as intended; variable area compressor stator vane positioning and bleed control with reset scheduling to anticipate and respond to transient excursions to improve the stall margin and operating characteristics; closed-loop modulated active clearance control systems to reduce blade tip wear and maintain design running clearance throughout the life of the engine; fuel flow staging to different zones of advanced, low emission combustors to minimize both low and high power emissions; modulated cooling air flow adjusted to optimum levels for cruise and takeoff to minimize cycle penalties. Advanced engine condition monitoring techniques would also be developed to detect engine degradation and reoptimize the control schedules for maximum efficiency.

This program with the resources given on Figure 11 would cover a five-year period and culminate in a system verification in an engine operating environment.

3.8.4 Engine/Airframe Integration

Propulsion system and aircraft vehicle aerodynamics are generally investigated independently of one another until very late in the preliminary design of aircraft systems. As a result, significant performance benefits are not realized. Sizable performance increases--on the order of 8-10 percent--are possible through the proper and early integration of the airframe and propulsion system. In military fighter aircraft, supersonic cruise aircraft, and VTOL aircraft, the integration of the engine system and the airframe is one of the most important aspects of the overall system design and can significantly affect airplane performance. Improved analytical design methods are required to reduce installation losses in the inlet, exhaust nozzle, and nacelle/pylon/wing flow interactions.

The overall objective would be to provide technology to reduce the installation losses associated with the integration of propulsion systems into advanced aircraft designs.

Basic theoretical and experimental research would be conducted to provide technology for the prediction of local flow interactions around the engine installation to exploit favorable interference effects which may enhance the wing lift, performance efficiency, reduce drag, and permit thrust reversing of the exhaust system to improve performance of the aircraft. For the exhaust nozzle, investigations would be made to determine means of improving the internal and external performance of both uninstalled and installed nozzles and to explore the integration procedures for incorporating the exhaust system into the fuselage, wing or pods. General experimental and theoretical research studies would be conducted to improve the understanding of the flow phenomena associated with nozzle/boattail/jet and jet/wing/airframe empennage interference. Finally, advanced analytical methods capable of predicting the propulsion system integration effects would be developed. Funding requirements are given on Figure 11.

3.9 FUNDAMENTAL TECHNOLOGY - AVIATION SAFETY

Operating problems arise most frequently when a new aircraft design is put into service, when a new air or ground operating environment is entered, or operating procedures are changed. The majority of these operating problems can be solved by straightforward engineering methods, calling upon established bases of knowledge or by modifications in operating techniques or procedures.

There is another class of operating problem, however, that is characterized by an elusiveness of cause or by a lack of sufficient understanding of how the airplane and its equipment will be operated and of the requirements placed upon the airplane and its equipment as it interacts with the environment. Solutions to these problems have generally required an expansion of knowledge or understanding of not only the nature of the problem, but also of the effects of employing different solution options with a view towards avoiding the creation of another problem. Research serves this purpose well by laying down the basis for development of new materials, systems, processes, operating techniques, and design practices which enable the establishment of a satisfactory safety margin or risk level. Very often though, an old problem which has been "solved" through research reappears, due to a change in aircraft type or change in operating environment. The new situation has uncovered a subtlety which necessitates a "finer scale" view of the earlier understanding. Additionally, situations have occurred where an improvement in design materials, or procedure undertaken for efficiency improvement or environmental benefit subtly introduces a new vulnerability to hazard, affecting the safety margins previously established.

The objective of the NASA aviation safety technology effort is to provide the technological basis for avoidance or elimination of the potentially serious hazards in the flight and ground operational environment. Reduction of operating problems, especially those environmentally created, will result in increased flight safety and efficiency and improved performance, while reducing the incidence of fatalities and injuries resulting from accidents.

The NASA aviation safety research program has been organized under major categories of aviation meteorology, aviation operations safety technology, and aircraft systems operating efficiency improvement research.

In the aviation meteorology research category are tasks dealing with low-altitude winds and gusts, high-altitude turbulence and storm systems, precipitation in the form of fog, rain, hail, and icing, and atmospheric electrical activity.

The aviation operations safety technology category includes research relating to hazardous situations or operational difficulties which are not well understood or for which corrective technology is not readily available. Examples of relevant research tasks are fire technology, accident survivability, safety fuels, detecting and warning of inflight hazards (e.g. clear air turbulence, fire, wind shear) and operational flight parameter statistics.

The research concerned with improving the operating efficiency of aircraft systems relates to landing gear systems, tires and brakes, runway surface effects and ground control criteria during taxiing, takeoff and landing. Improvements in aircraft systems can be translated directly into increased safety and operational reliability for all aircraft types as well as into reduced operating costs.

With this background, four critical areas have been identified for increased emphasis in fundamental technologies beyond the presently planned ongoing program levels for safety technology. Accordingly, the following paragraphs contain details of possible aviation safety technology initiatives in the areas of aircraft icing protection, fire resistant materials engineering, transport accident survivability, and characterization of lightning hazards.

3.9.1 Aircraft Icing Protection

Weather represents the major uncontrollable variable impacting flight operations. It is a significant factor in delays encountered in air traffic operations and is a major contributor to aviation accidents. Whereas rapid climb rates and high cruise altitudes of modern jet transports have offset hazards posed by icing to a great degree, the hazards posed by icing continue as serious problems for general aviation aircraft and rotorcraft, and for civil aircraft which in commuter service operate predominantly in the lower altitudes. A reexamination and update of icing technology as it applies to present and anticipated aircraft designs is badly needed, as concluded by the several working committees at a July 1978 Government/industry aircraft icing workshop sponsored by NASA and FAA.

The objective of this effort would be to expand and update the 25-year old icing technology base to bring it into alignment with modern fixed- and rotary-wing flight vehicle design and operational requirements. The Lewis Research Center, site of the current NASA icing research wind tunnel and source of the earlier NACA icing activity, would lead this program augmentation effort.

The approach to improving aircraft icing technology would include (1) upgrading and expanding icing research facilities, (2) updating criteria for assessing and defining ice hazards, (3) exploring new ice control concepts, and (4) improving ice simulation and icing test techniques. Component, system, and model studies and experiments would be conducted with a breadth of effort which would establish a technology data base in recognition of the constraints peculiar to both fixed- and rotary-wing aircraft. The augmented program effort would be conducted over a seven-year period, with funding requirements as shown in Figure 12.

3.9.2 Fire Resistant Materials Engineering

In the late 1960's, a series of civil aircargo fire accidents directed Government and industry attention to the task of improving the fireworthiness of materials used in aircraft interiors, to provide increased safety from fire, smoke, and incapacitating gases. NASA expanded its work in spacecraft materials research to explore possible applications to aircraft fireworthiness, with major concentration on advanced polymeric materials. FAA and other researchers have concentrated on examining the fireworthiness aspects of an array of commercially-available materials. Promising laboratory materials began to appear in the early 1970's and a five-year FIre REsistant Materials ENgineering (FIREMEN) program augmentation within NASA was begun in 1975 to accelerate their evaluation and application. Involvement of the major aircraft manufacturers in FIREMEN is resulting in NASA-developed advanced polymeric materials of improved fireworthiness being substituted for presently used cabin and cargo bay panel and liner materials. Because of the success with the original five-year FIREMEN program, both industry and airline users of this advanced materials technology strongly urge NASA to extend the program into a second phase, capitalizing on program momentum, continuing the accelerated development of fire-resistant aircraft materials, improving the rigor and realism of fire modeling and testing methods, and determining the feasibility of safety fuel concepts, e.g. anti-misting kerosene. The following program is designed to respond to these expressed needs.

The objective of a FIREMEN-II program would be to continue the accelerated practical application of aircraft fireworthiness research results in order to minimize the loss of life and hull damage due to fire and its effects. This multi-center effort (Ames, Johnson, and Lewis Research Centers) would be led by the Johnson Spacecraft Center and would be coordinated closely with FAA fire technology R&D which is conducted in support of regulatory requirements.

The approach for FIREMEN II would be to (1) develop and assess new materials, (2) determine feasibility of anti-misting kerosene concepts, (3) improve the rigor and realism of fire modeling (prediction) and testing methods, and (4) develop fireworthiness criteria. It would also be planned to broaden the NASA effort into toxicity evaluation methods, toxic threat modelling, and survivability assessment techniques. This program would build on the current FIREMEN program data and experience base, maximizing participation by industry, and would be closely coordinated with, and periodically review by, interested Government and industry representatives and groups.

The FIREMEN II effort would be conducted over a six-year period and will require funding as shown in Figure 12.

3.9.3 Improved Transport Structural Integrity

The highly successful NASA crashworthiness program for General Aviation has focused on development of analytical methods and design techniques based on full-scale crash tests in support of load-absorbing protective structure, seats, and restraint systems. The potential benefits to occupant survival of advanced structural design concepts for improved crashworthiness in combination with improved fire resistance may enable future aircraft to have inherently greater crashworthiness. Although a transport aircraft fire technology program is well underway (e.g. FIREMEN), there is no major effort for improving structural crashworthiness similar to that for general aviation. There is a need to fill that void.

The objective of an Improved Transport Structural Integrity program would be to develop technology for improving the structural crashworthiness of state-of-the-art (metallic) and advanced (composite) aircraft structures in order to enlarge the envelope of impact-survivable accidents. The initial phase of this program would consist of (1) basic structural analysis and research to update crashworthiness criteria for transport category aircraft fuselage and wet fuel areas, (2) examination of improved seat design concepts, (3) extension of crashworthiness technology to nonmetallic and hybrid metallic/composite structures, and (4) integration of improved structural integrity and fireworthiness technology to increase the design data base to support a higher level of operational protection and occupant survivability in accidents. A final task in this initial phase would be to define a Phase II effort which would validate these advanced structural concepts in large-scale component tests and full-scale crash tests.

The Phase I effort for improved transport structural integrity would be conducted over a six-year period and would require funding as shown in Figure 12.

3.9.4 Lightning Hazards Technology

Hazards to flight are posed by both frontal and isolated storm systems in the form of turbulence, tornadic winds, precipitation as rain or hail, and electrical activity. While considerable study of storms has been and is being done, fine-scale definitions of storm hazards and their boundaries continue to elude us in terms of functional use to designers and operators of aircraft. Problems exist both in the characterization of the hazards as well as in the lack of detecting, warning, or sensing equipment which can be used aboard the aircraft or on the ground to size the areas or volume of hazard and track its movement to enable safe but not inefficient avoidance of hazard. Of special concern is lack of data which characterize lightning and atmospheric electrostatic charges in flight, and lack of instrumentation which can make accurate broad band inflight measurements of induced currents and electromagnetic fields from lightning and atmospheric electricity.

The objective of this program element would be to determine the full range of atmospheric electrical hazards to modern aircraft and their systems in order to provide a rational basis for avoidance of these hazards. An augmentation would accelerate the study of atmospheric electrical phenomena in terms of safe aircraft operation. In conjunction with FAA, NOAA, and USAF, NASA would build on previous lightning research to characterize energy levels associated with strikes to the aircraft itself, and to determine the effects of such strikes on metallic and nonmetallic skins and structures, avionics and electrical power systems, flight control systems, and power plant and fuel systems. The outputs of this effort would be an expanded understanding of protection through design, as well as a base for possible hazard detection and avoidance devices.

Fundamental to lightning research with airborne vehicles is the availability of suitable instrumentation. Thus, the initial task is to accelerate development and validation of an isolated multi-sensor data acquisition system for precise, broadband, inflight measurements of data such as induced currents and voltages, electromagnetic and electrostatic fields, acoustic pressure/shock wave intensities, and rapid rates of change of these parameters. Next, flight research would be conducted to characterize the lightning environment, to better define the hazard to aircraft, and to investigate the relationship between flight and ground-based lightning measurements. Finally, protection design concepts would be explored for aircraft electrical and electronic systems, structures, and fuel systems.

A fully-instrumented F-106B airplane would be utilized initially in a joint program with the National Severe Storms Laboratory to investigate the location and correlation of various hazards within severe storms. Special additional flights would be made as necessary to obtain lightning strike data. An airplane more representative of the transport category could be used in later parts of the flight program.

This work and the work being accomplished or planned by other agencies would be assessed, incorporated, expanded, etc., as feasible to provide a basis for improved design, validation procedures, and criteria for aircraft operations in the presence of lightning. Particular areas of consideration are (1) the relationship of lightning to the operational environment, (2) detection and avoidance, (3) prediction, (4) protection, (5) ground test and protection validation techniques, and (6) pilot training relative to expected effects of lightning.

The lightning hazards technology program enhancement is planned over a period of seven years, with required funding as shown in Figure 12.

3.10 FUNDAMENTAL TECHNOLOGY - AVIONICS AND HUMAN FACTORS

Undoubtedly the single most important factor driving new opportunities in avionics and controls is the explosive growth in microelectronics and associated technologies. The U.S. industry and Government R&D efforts to exploit that potential for aeronautics has seriously lagged the capability provided by microelectronics. An aggressive NASA R&D program could yield substantial benefits in terms of improved aircraft efficiency, extended operational capability and, through supporting technology to FAA, improved flight operations and traffic management. Examples of tangible payoffs would be: enhanced safety; lower design, operational and spares inventory costs; higher reliability and improved maintainability; increased air transportation system capacity; freer airspace and improved aircraft performance. A major R&D thrust would also permit the U.S. to counter the growing threat of foreign competition in avionics and controls and aid in maintaining (or recapturing in some areas) the world leadership role traditional for U.S. industry in aeronautics. If NASA were to assist in meeting the challenge presented by microelectronics, the necessary research and development involving industry, universities and the user community would require a major increase in resources over the next five to ten years.

A special NASA intercenter team working with industry and university advisors and representatives from other Government agencies has drafted an avionics, controls and human factors technology plan which is now under review. It proposes a major program to develop technologies that are very broad in their application as well as selected technologies that are unique to specific vehicle classes such as active vibration control in helicopters. The focused efforts proposed for specific vehicle types have been discussed under the individual vehicle headings. The technology opportunities that are broadly applicable, which include advanced aircraft controls, crew station technologies, flight management and integration and interfacing technologies, are described in this section.

3.10.1 Aircraft Controls

Aircraft control technology includes both the functional requirements of flight control, which typically have interdisciplinary dependence, and system mechanism concepts, such as redundant digital control systems. The key subelements are applied controls technology, and advanced hybrid flight control systems technology.

The applied controls technology subelement specifically addresses the control law or functional definition of control such as the interdisciplinary design aspects of active controls. A Phase I effort would emphasize design methodology and criteria while exploring new concepts in applied controls, particularly the interactions with other disciplines. Analysis, simulation and selected experiments, including some flight testing, would be used to investigate interactive effects on design and criteria. Phase II would progress to concept development involving interdisciplinary design teams with industry and evaluation of design methodology utilizing simulation and experiments in ground facilities. The major validation effort would be in Phase III using an applied controls research aircraft and/or other in-house and contractor facilities with industry evaluation teams.

System concepts for mechanizing the control laws would be addressed in the advanced hybrid flight controls subelement. The main thrust would be to develop concepts for ultra-reliable systems for flight crucial functions which would be a major step towards a lifetime control concept. Conceptual studies of several approaches including digital and hybrid analog/digital would be performed under contract in Phase I. The most promising approach would be developed in Phase II for a proof-of-concept flight research program conducted as Phase III. Funding requirements for the three phases are shown in Figure 13.

3.10.2 Crew Station Technologies

Aircraft of the future will fly in more crowded skies, under more stringent environmental regulations, in a more complex air traffic control environment, operating in more severe weather minima, and with more expensive fuel. Safe and efficient flight in this environment requires more precise and flexible navigation in space and time, mated to an advanced air traffic management system. A Crew Station Technology program would develop and exploit the man-machine system opportunities for meeting these requirements. The opportunities exist because of major advances in display concepts, media, and generation techniques, time-shared multifunction displays/controls, distributed microprocessor hardware/software for control/display management, etc., coupled with improved human factors insights. If all this could be put together properly, safety would be enhanced by the reduction in human error potential and pilot/crew workload, cockpit panel space would be better utilized while pertinently timed and appropriate data is presented, and operational capability would be improved by elevating the pilot from a controller to a flight operations manager.

At the outset of Phase I of such a program, the promising generic military crew station technology, including multi-legend switching, wide field of view head-up-displays, and voice synthesis and recognition, would be examined for transfer to the civil segment. NASA would expand its efforts with DOD to accelerate the development of high risk, long lead time technologies, e.g. flat panel display media. A systems integration portion (Phase II) of the advanced crew station avionics program subelement would culminate (in Phase III) with the development, demonstration, and assessment of totally-integrated advanced crew stations.

An increasingly important aspect of crew station technology is the interactive transfer of information in the man-machine context. This would be an important feature in the crew station human factors subelement, intended to develop improved techniques for forecasting and quantifying the impact of changes in display and control hardware and system operating procedures on pilot behavior and performance, and to provide human factor guidelines for display simplification and improved information transfer.

Funding requirements for this activity are shown in Figure 13.

3.10.3 Flight Management

Flight management technology encompasses all the factors governing the precise and safe movement of aircraft through the airspace, i.e. navigation, communications, crew operations, and interactions with air traffic control (ATC). FAA has the responsibility for defining and implementing the future ATC system to meet the growing demands. An important NASA role is to work with DOT/FAA, the industry, the aviation community and other agencies to develop advanced avionics, controls and associated technologies for improving flight operations and traffic management within the capability of the evolving ATC system. The two most important and appropriate generic areas for potential increases are: (1) navigation and guidance; and, (2) flight information management.

The activities in the navigation and guidance subelement would include investigations of both emerging technologies that could be implemented within the current and projected National Airspace System (NAS), and new concepts that could provide long-range opportunities for major improvements in the NAS. Emerging technology concepts to be investigated in Phase I range from advanced inertial and hybrid navigation systems to the NAVSTAR/Global Position System (GPS) being developed for military use. NASA's joint program with FAA to explore the civil potential of NAVSTAR/GPS, which addresses the low cost user equipment question, would be expanded to conduct limited flight investigations of accuracy, interference effects and operational considerations using an experimental receiver.

In March 1978, the FAA held a Consultative Planning Conference on New Engineering and Development Initiatives--Policy and Technology Choices, which was the "kick-off" for an intensive seven-month consultation activity with all major sectors of the aviation community including NASA. Five topic groups were organized to evaluate the critical issues as follows: Productivity and Automation; Airport Capacity; Freedom of Airspace; Safety and Flight Control; and, Non- or Low-Capital Policies to Improve Efficiency. Many of the recommendations in their published report, March 1979, specifically address flight management technologies. A second thrust of NASA's proposed program would provide technology options such as those identified in the FAA report, for long-range opportunities in flight management in support of FAA's long-range plan. Particular emphasis will be placed on technology that could substantially reduce the cost of providing satellite based services. Close coordination will be maintained with FAA in selecting promising concepts to be investigated and developed further in Phase II. Select ones will be evaluated in Phase III through flight tests.

Another closely coupled potential program area for increased NASA support is flight information management, which addresses the human role in future aviation systems. It is an important factor in the study of the long-range opportunities discussed above, but more importantly research in this area can provide a continuum of results for existing, emerging and future systems. At the present time, 70-90 percent of all aircraft accidents involve human error. Incorrect or incomplete information transfer from displays to the crew, from the crew to a system (data entry), among the crew, between crew and ATC, between two air traffic controllers or among several pilots and controllers are often the key factors. The objectives of this subelement are to provide guidelines for the most effective information management and specific human factors guidance in the development and evaluation of emerging systems and new concepts. The subelement would consist of a series of well-controlled experiments ranging from part-task simulation to full-mission simulation using a large sample of operational airline crews to systematically investigate information transfer and human errors. Most of the research would be conducted in a Man-Vehicle Systems Research Facility with selected flight test verifications in Phase II on existing NASA research aircraft.

Funding requirements are presented in Figure 13.

3.10.4 Integration and Interfacing Technologies

Integration and Interfacing technology is treated as a distinct element because of the growing importance of effective, efficient and reliable integration and/or interfacing within large complex systems. The generic aspects are those concepts, system elements and methods that could be applied or adapted to a wide variety of integrated systems that designers might include in a total aircraft design. The output of this research would be validated system concepts and assessment methodology, not specific integrated systems. The concepts and methodology would be adaptable to various levels of systems integration such as an integrated cockpit display panel, integrated flight and propulsion controls, or the entire suit of avionics as in the Air Force Digital Avionic Integrated System (DAIS).

The subelements are system elements research, integration methodology and assessment methodology in Phase I and environmental effects in Phase II.

The objectives of system elements research are to investigate advanced concepts, e.g. fault-tolerant computing, that are key to promising new integrated system architectures and to develop the associated interfacing technologies, e.g. data and power distribution systems and automatic maintenance aides. Architectural concepts for fault-tolerant and distribution networks systems would be explored which are a significant departure from the concepts being investigated under the on-going program. For example, the use of massive redundancy made possible by Very Large Scale Integrated (VLSI) circuits, combined with network data distribution and functionally distributed architectures.

The principal objective of integration methodology research is to develop techniques of functional and physical integration of avionics and controls hardware and software. A major thrust is included to develop software methodology such as structured programming techniques for avionics, evaluation of DOD standard high level languages to determine the best ones for civil avionics, and methods for optimally locating software modules between distributed processors to reduce bus traffic and inter-communication overhead.

As we move into the era of ultra-reliable systems, an extremely important subelement is that of assessment methodology research. This includes the development of reliability analysis techniques for ultra-reliable systems; performance, safety, and economic modeling; system validation techniques with emphasis on highly reliable and fault-tolerant systems; evaluation methods for new computer chips using gate level emulation techniques; and, development of methods for evaluating failure probability characteristics of fault-tolerant computers. Software reliability assessment would receive a significant increase in attention, especially for distributed, fault-tolerant processors and systems with reconfigurable attributes. Design proof methodologies coupled with test techniques would be developed to verify design, facilitate reliability analysis, and assure the system is meeting its design goals.

The final subelement is the investigation of environmental effects. Such research includes the evaluation of the lightning threat and electromagnetic interference effects on digital avionics and controls and the investigation of methods for reducing the threat. This activity is a companion program to the hazard definition part of the NASA Aviation Safety Program, which will develop a comprehensive, accurate definition of the lightning hazard. The lightning hazard model would provide the basis for analytical/computer-aided techniques for lightning protection methods design and for development of ground-based laboratory lightning simulation test techniques for avionic systems. The analytical/computer-aided design approach would be applied to selected digital systems and united with the laboratory simulated lightning test to achieve a system for demonstration in an in-flight strike test as an auxiliary experiment on operational aircraft.

Funding requirements and schedules for these activities are shown in Figure 13.

4. CONCLUDING REMARKS

The foregoing sections have addressed potential new focused initiatives which, like ACEE, might be superposed over NASA's ongoing aeronautical research and technology programs to facilitate future development of greatly improved U.S. civil aeronautical products. The discussions have outlined the technical, market, and economic factors which influence decisions as to the importance, the nature, the scope, and the timing of such initiatives as additions to the ongoing programs.

The discussion is not intended as a discussion of the entire aeronautical research effort. In general, the ongoing NASA programs as presently constituted include considerable activity in each of the areas cited as possible subjects for additional focus. Only the major aspects of these ongoing activities have been summarized in this paper. The present paper has not reviewed in any depth the very important ongoing basic research and technology programs, nor has it discussed the activities related to vehicle types (e.g., hypersonic aircraft or lighter-than-air vehicles) not yet identified as credible candidates for near-term major additional emphasis.

Future focused program possibilities, addressing both near-term and far-term potential applications, emerge continuously from research and technology base and specific vehicle-oriented activities. The options discussed in this paper represent a snapshot of the major possibilities as seen at this time, rather than a set of specifically recommended programs. Evolution of the overall NASA aeronautics program will be based on future consideration of these possibilities and assessment of additional needs and opportunities perceived in the course of time.

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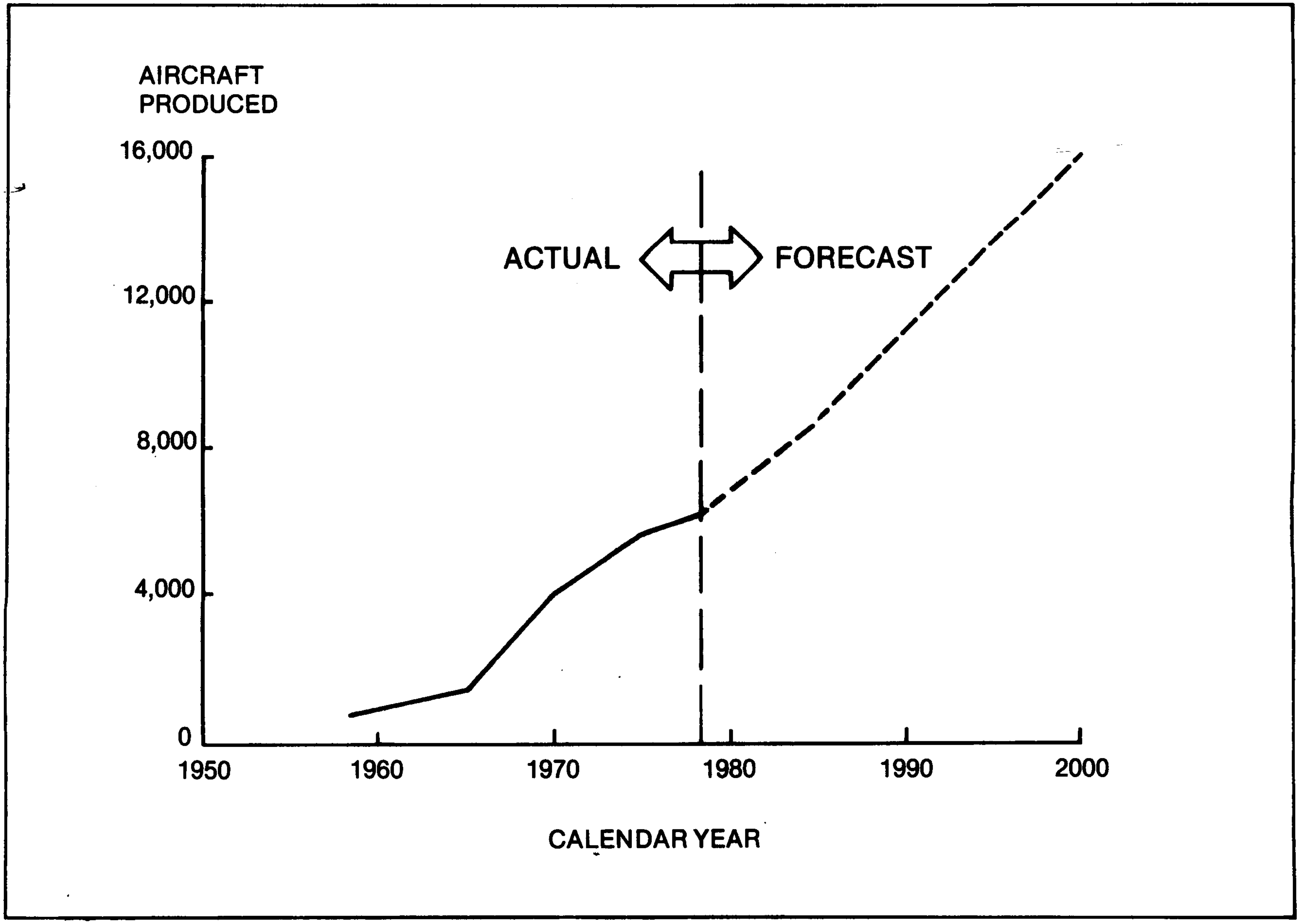
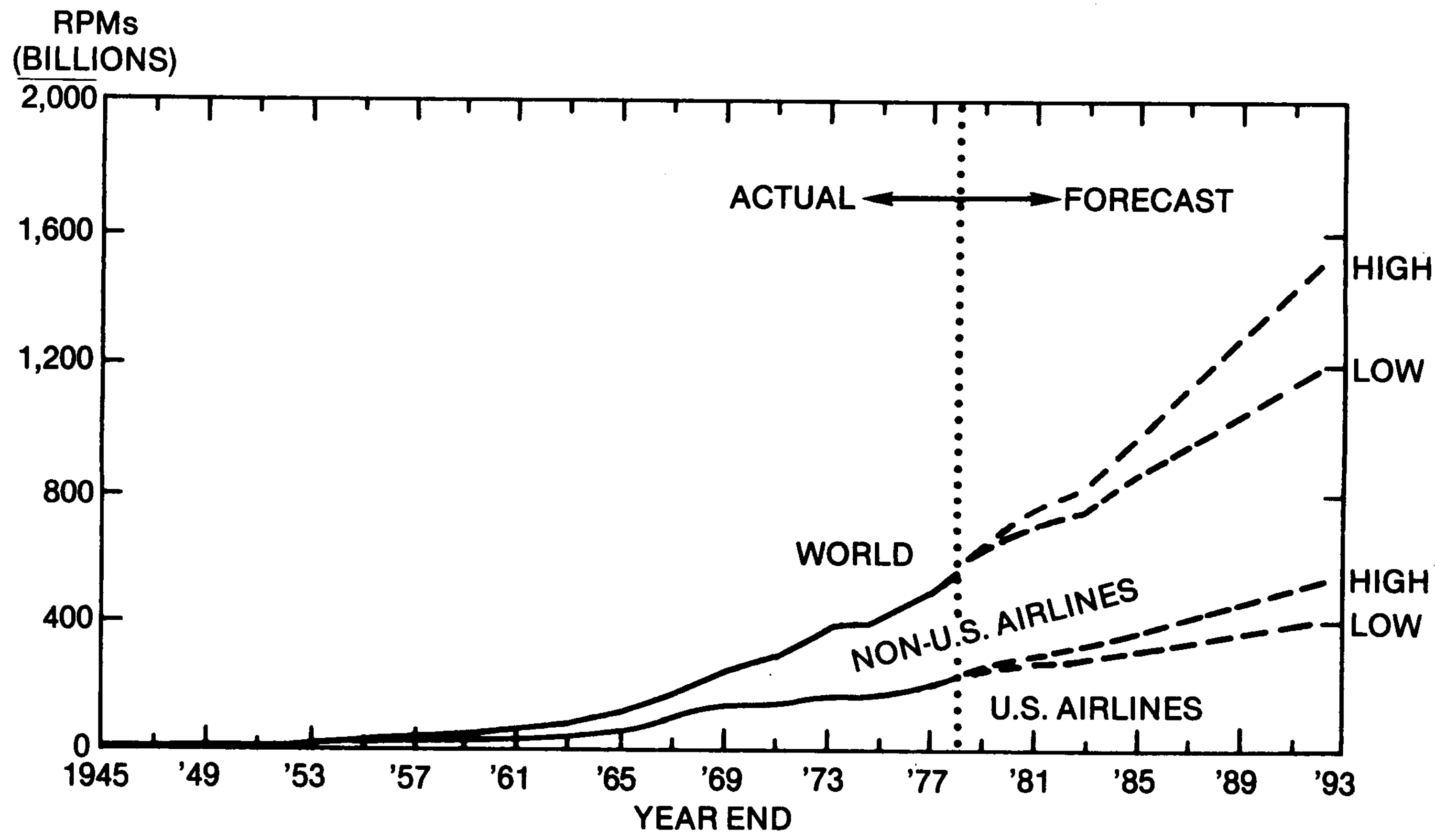


FIGURE 1

CUMULATIVE PRODUCTION OF LARGE COMMERCIAL JET TRANSPORTS, 1958—2000



NOTE:
EXCLUDES U.S.S.R., PRC, AND OTHER COUNTRIES,
BUT INCLUDES TAIWAN AND ALL-CHARTER CARRIERS

FIGURE 2
HISTORIC AND FORECAST WORLDWIDE REVENUE PASSENGER-MILES

ELEMENTS	YEAR 1	2	3	4	5	6	7	8	9	10	TOTAL
ADVANCED TCV TECHNOLOGY		3.0	7.0	7.0	16.0	15.0	10.0	10.0	4.0		72.0
ADVANCED COMMERCIAL ENGINE TECHNOLOGY											
PHASE I		2.0	5.0	8.0	8.0	7.0					30.0
PHASE II						7.0	12.0	16.0	10.0	0	45.0
ACTIVE CONTROLS TECHNOLOGY											
PHASE I			3.0	3.0	5.0	3.0	2.0	2.0	2.0	1.0	21.0
PHASE II						7.0	5.0	5.0	5.0	2.0	24.0
AVIONICS AND CONTROLS INTEGRATION											
PHASE I			1.5	2.5							4.0
PHASE II					6.0	31.0	23.0	7.0	5.0	4.0	76.0
LARGE COMPOSITE PRIMARY STRUCTURES	4.0	12.0	23.0	38.0	30.0	12.0					119.0
TOTALS	4.0	17.0	39.5	58.5	65.0	82.0	52.0	40.0	26.0	7.0	391.0

FIGURE 4

SCHEDULE AND FUNDING (FY81 $,M)— SUBSONIC TRANSPORTS

ELEMENT	YEAR 1	2	3	4	5	6	7	8	TOTAL
PROPULSION TECHNOLOGY									
• VARIABLE FLOW PROPULSION SYSTEMS	6.5	9.0	10.5	10.0	7.0				43.0
• ADVANCED CORE		10.0	15.0	17.0	13.0	10.0			65.0
• VARIABLE CYCLE EXPERIMENTAL ENGINE				10.0	74.0	85.0	85.0	46.0	300.0
AIRFRAME TECHNOLOGY									
• NACELLE/AIRFRAME INTEGRATION		4.0	5.0	8.0	8.0	6.0			31.0
• HIGH-SPEED STRUCTURES		4.0	10.0	13.0	14.0	9.0			50.0
AIRCRAFT SYSTEMS TECHNOLOGY									
• HIGH-SPEED RESEARCH AIRCRAFT DEFINITION		3.0	5.0	7.0	4.0				19.0
• HIGH-SPEED RESEARCH AIRCRAFT					TO BE ESTABLISHED BY DEFINITION PHASE				
• TECHNOLOGY VALIDATION			35.0	38.0	40.0	41.0			154.0
TOTALS	6.5	30.0	80.5	103.0	160.0	151.0	85.0	46.0	662.0

FIGURE 5

SCHEDULE AND FUNDING (FY81 $,M)—SUPERSONIC TRANSPORTS

ELEMENTS	YEAR 1	2	3	4	5	6	7	8	9	10	TOTAL
LARGE CARGO AIRCRAFT AND SYSTEMS											
PHASE I	2.0	3.0	5.0	4.0	2.0						16.0
LARGE CARGO AIRCRAFT											
PHASE II				TO BE ESTABLISHED BY PHASE I							
TOTALS	2.0	3.0	5.0	4.0	2.0						16.0

FIGURE 6

SCHEDULE AND FUNDING (FY81 $,M)—LARGE CARGO/LOGISTIC AIRCRAFT

ELEMENTS	YEAR 1	2	3	4	5	6	7	8	TOTAL
CRYOGENIC-FUEL AIRCRAFT PHASE I	4.0	4.0	6.0	6.0	3.0				23.0
TERMINAL SYSTEM FOR CRYOGENIC-FUEL AIRCRAFT		1.0	3.0	8.0					12.0
CRYOGENIC-FUEL AIRCRAFT PHASE II				TO BE ESTABLISHED BY PHASE I					
TOTALS	4.0	5.0	9.0	14.0	3.0				35.0

FIGURE 7

SCHEDULE AND FUNDING (FY81 $,M)—CRYOGENIC-FUEL TRANSPORTS

ELEMENTS	YEAR 1	2	3	4	5	6	7	8	9	10	11	TOTAL
AERODYNAMICS & STRUCTURES												
• AERODYNAMICS/ACOUSTICS												
PHASE I	2.0	4.6	6.3	3.1								16.0
PHASE II			3.3	6.0	5.7	2.0						17.0
PHASE III						1.9	2.5	3.8	6.6	5.6	2.6	23.0
• VIBRATION REDUCTION												
PHASE I	3.0	6.5	5.5	2.0								17.0
PHASE II			2.4	3.3	1.9	1.4						9.0
PHASE III			1.9	4.4	6.4	3.8	2.5					19.0
PHASE IV						1.0	2.5	6.4	3.8	3.2	3.1	20.0
• COMPOSITE AIRFRAME												
PHASE I		2.5	2.5	5.1	3.8	3.1						17.0
PHASE II						3.8	8.9	8.9	7.6	2.8		32.0
FLIGHT CONTROL & AVIONICS SYSTEMS												
• ALL-WEATHER SYSTEMS												
PHASE I	3.0	6.5	4.5									14.0
PHASE II		4.7	7.9	5.6	3.8							22.0
PHASE III					3.6	5.7	5.1	3.8	3.8			22.0
• ACTIVE CONTROL SYSTEMS												
PHASE I			3.3	7.4	9.8	9.5						30.0
PHASE II							7.4	6.7	3.8	4.1		22.0
SUB-TOTALS	8.0	24.8	37.6	36.9	35.0	32.2	28.9	29.6	25.6	15.7	5.7	280.0

FIGURE 8A

SCHEDULE AND FUNDING (FY81 $,M)—ROTORCRAFT

ELEMENTS	YEAR 1	2	3	4	5	6	7	8	9	10	11	TOTAL
PROPULSION												
• ENGINE COMPONENTS												
PHASE I	3.0	8.0	11.9	5.1	2.0							30.0
PHASE II				4.6	7.4	6.7	3.3					22.0
PHASE III							3.2	4.8	5.4	4.6		18.0
• POWER TRANSFER												
PHASE I		2.5	3.8	5.1	4.6							16.0
PHASE II						4.1	3.8	4.2	5.9			18.0
• SYSTEMS INTEGRATION												
PHASE I				3.8	9.5	10.8	6.9					31.0
VEHICLE CONFIGURATIONS												
• HIGH SPEED												
PHASE I	2.5	8.9	9.5	5.1								26.0
PHASE II				7.6	10.2	7.6	3.8	2.8				32.0
• LARGE ROTORCRAFT												
PHASE I	1.5	3.2	5.1	3.6	2.6							16.0
PHASE II					1.3	3.8	6.4	6.4	6.1			24.0
SUB-TOTALS	7.0	22.6	30.3	34.9	37.6	33.0	27.4	18.2	17.4	4.6	0	233.0
SUB-TOTALS FROM FIGURE 8A	8.0	24.8	37.6	36.9	35.0	32.2	28.9	29.6	25.6	15.7	5.7	280.0
TOTALS	15.0	47.4	67.9	71.8	72.6	65.2	56.3	47.8	43.0	20.3	5.7	513.0

FIGURE 8B

SCHEDULE AND FUNDING (FY81 $,M)—ROTORCRAFT (CONT'D)

	YEAR						
ELEMENT	1	2	3	4	5	6	TOTAL
SMALL TRANSPORT AIRCRAFT TECHNOLOGY							
PHASE I	2.0	2.0					4.0
PHASE II			4.0	5.5	8.0	8.5	26.0
TOTALS	2.0	2.0	4.0	5.5	8.0	8.5	30.0

FIGURE 9

SCHEDULE AND FUNDING (FY81 $,M)—COMMUTER TRANSPORTS

ELEMENT	YEAR 1	2	3	4	5	6	7	8	TOTAL
PROPULSION									
• ADVANCED PROPELLERS	1.5	2.0	1.0	1.0	0.5				6.0
• ADVANCED INTERNAL COMBUSTION ENGINES		2.0	3.0	3.0	2.0	1.5			11.5
• TURBINE ENGINES		2.0	7.0	13.0	16.0	11.0			49.0
AERODYNAMICS & STRUCTURES									
• NATURAL LAMINAR FLOW WING TECHNOLOGY		0.9	1.0	1.0	0.7	0.7			4.3
• AERIAL APPLICATIONS SYSTEM TECHNOLOGY		0.8	1.0	1.0	1.3	1.3			5.4
• COMPOSITE STRUCTURES TECHNOLOGY		0.8	1.0	2.0	3.0	1.0			7.8
AVIONICS, CONTROL & DISPLAY		1.0	2.0	3.5	6.0	8.0	9.5	5.0	35.0
TOTALS	1.5	9.5	16.0	24.5	29.5	23.5	9.5	5.0	119.0

FIGURE 10

SCHEDULE AND FUNDING (FY81 $,M)—GENERAL AVIATION

ELEMENT	YEAR 1	2	3	4	5	6	7	8	9	10	TOTAL
ALTERNATE FUELS											
• NEAR TERM	4.0	10.0	13.0	13.0	10.0						50.0
• FAR TERM			2.0	4.0	8.0	10.0	13.0	13.0	10.0	7.0	67.0
ENGINE DURABILITY											
• DESIGN DEFINITION	2.5	8.5	9.5	8.5	5.5						34.5
• COMPONENT DEFINITION			1.5	3.0	5.5	8.5	6.8				25.3
ENGINE CONTROLS		3.0	4.0	6.0	3.0	2.0					18.0
ENGINE/AIRFRAME INTEGRATION	1.0	1.0	2.0	3.0	5.0						12.0
TOTALS	7.5	22.5	32.0	37.5	37.0	20.5	19.8	13.0	10.0	7.0	206.8

FIGURE 11

SCHEDULE AND FUNDING (FY81 \$,M)—PROPULSION

ELEMENT	YEAR 1	2	3	4	5	6	7	TOTAL
AIRCRAFT ICING PROTECTION	1.0	1.7	2.0	2.0	1.5	1.5	1.5	11.2
FIRE RESISTANT MATERIALS ENGINEERING II	1.2	2.5	2.5	2.8	3.0	1.0		13.0
IMPROVED TRANSPORT STRUCTURAL INTEGRITY	1.0	2.0	2.5	4.0	4.0	5.5		19.0
LIGHTNING HAZARDS TECHNOLOGY	0.6	1.5	1.2	1.2	1.2	1.1	0.9	7.7
TOTALS	3.8	7.7	8.2	10.0	9.7	9.1	2.4	50.9

FIGURE 12

SCHEDULE AND FUNDING (FY81 $,M)—AVIATION SAFETY

ELEMENT	YEAR 1	2	3	4	5	6	7	8	9	10	TOTAL
AIRCRAFT CONTROLS											
PHASE I	3.7	7.6	9.0	8.6	6.7	5.9	5.3	5.3	5.3	5.3	62.7
PHASE II		3.7	10.9	18.4	17.1	9.9	5.0	3.5			68.5
PHASE III				1.0	1.5	3.1	4.5	4.9	2.2	0.3	17.5
CREW STATION TECHNOLOGIES											
PHASE I	1.4	3.4	4.0	4.5	4.7	2.2	1.3	1.3	1.3	1.3	25.4
PHASE II		1.9	2.4	3.2	4.3	3.8	2.0				17.6
PHASE III				1.6	3.0	3.4	2.9	2.7	2.5	1.9	18.0
FLIGHT MANAGEMENT											
PHASE I	2.0	4.7	3.4	2.0	0.4						12.5
PHASE II		4.0	5.5	6.5	5.0	3.8	2.7				27.5
PHASE III				3.2	9.3	13.8	14.8	11.6	5.5	3.0	61.2
INTEGRATION AND INTERFACING TECHNOLOGIES											
PHASE I	1.4	4.1	7.5	8.4	5.4	1.3	0.3	0.3	0.3	0.3	29.3
PHASE II		0.8	4.0	4.0	3.4	1.5	1.0				14.7
TOTALS	8.5	30.2	46.7	61.4	60.8	48.7	39.8	29.6	17.1	12.1	354.9

FIGURE 13

SCHEDULE AND FUNDING (FY81 $,M)—AVIONICS AND HUMAN FACTORS